

USAFETAC/PR--91/011

AD-A240 486



(2)



C-29A AIRCRAFT ALTIMETER ERRORS

by

William R. Schaub, Jr.



JUNE 1991

DTIC
ELECTED
SEP 17 1991
S B D

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION IS UNLIMITED

91-10639



USAF
ENVIRONMENTAL TECHNICAL
APPLICATIONS CENTER

Scott Air Force Base, Illinois, 62225-5438

91 9 13 024

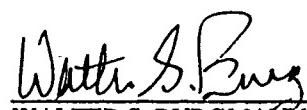
REVIEW AND APPROVAL STATEMENT

USAFETAC/PR--91/011, C-29A Aircraft Altimeter Errors, June 1991, has been reviewed and is approved for public release. There is no objection to unlimited distribution of this document to the public at large, or by the Defense Technical Information Center (DTIC) to the National Technical Information Service (NTIS).



PATRICK J. BREITLING
Chief Scientist

FOR THE COMMANDER



WALTER S. BURGMANN
Scientific and Technical Information
Program Manager
7 June 1991

REPORT DOCUMENTATION PAGE

2. Report Date: June 1991.
3. Report Type: Project Report
4. Title: C-29A Aircraft Altimeter Errors
6. Authors: William R. Schaub, Jr.
7. Performing Organization Name and Address: USAF Environmental Technical Applications Center (USAFETAC/DNO), Scott AFB, IL 62225-5438
8. Performing Organization Report Number: USAFETAC/PR--91/011
12. Distribution/Availability Statement: Approved for public release; distribution is unlimited.
13. Abstract: This report documents the results of a study initiated to solve problems with pressure altimeter errors (differences between indicated and true altitude) aboard Air Force C-29A flight inspection aircraft. A basic review of altimetry is provided, along with an explanation of how atmospheric changes affect barometric pressure and pressure altimeters. A method for in-flight correction of altimeter errors is provided, along with an appendix that gives monthly error statistics for the three C-29A working flight levels (1,000, 1,500, and 2,000 feet above ground level). Although the results of this study are only applicable to Scott Air Force Base, Illinois, they can be considered generally representative of other stations with similar field elevations in the midwestern United States. USAFETAC has the ability to produce climatological altimeter error data for any location from which representative upper-air and surface observations are available.
14. Subject Terms: CLIMATOLOGY, ATMOSPHERIC PRESSURE, ATMOSPHERIC TEMPERATURE, BAROMETRIC PRESSURE, BAROMETRY, ALTIMETRY, ALTIMETERS, NAVIGATIONAL AIDS, ALTITUDE, FLIGHT INSPECTION, C-29A, SCOTT AFB, ILLINOIS
15. Number of Pages: 39
17. Security Classification of Report: Unclassified
18. Security Classification of this Page: Unclassified
19. Security Classification of Abstract: Unclassified
20. Limitation of Abstract: UL

Standard Form 298

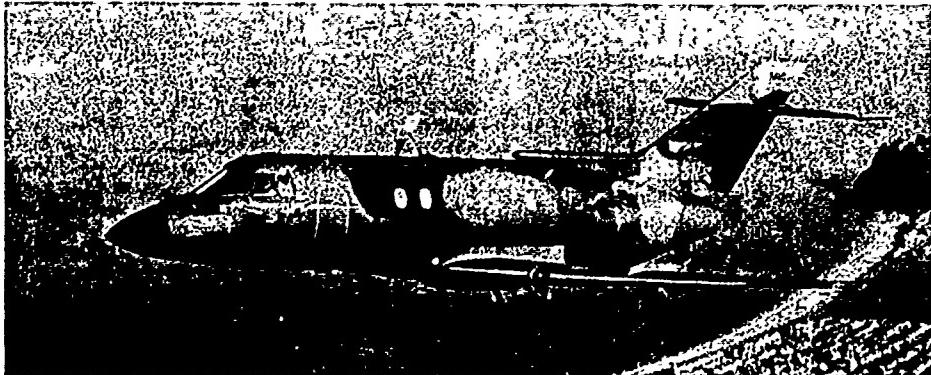
PREFACE

This report documents the results of USAFETAC Project 900807, "C-29A Aircraft Altimeter Errors." The analysts were Mr William R. Schaub, Jr., and Major Walter F. Miller, USAFETAC/DNO.

The 375th Military Airlift Wing (through Detachment 9, 17th Weather Squadron) asked USAFETAC to investigate and describe the weather factors that cause pressure altimeter errors (departures of indicated aircraft altitude from true altitude) in its C-29A flight inspection aircraft. The customer also asked for estimates of the magnitude of altimeter error for typical C-29A missions at flight levels of 1,000, 1,500, and 2,000 feet AGL, along with methods for calculating the error in flight.

In this study, USAFETAC/DNO provides a review of basic altimetry principles, with descriptions of typical atmospheric phenomena and their effects on pressure surfaces. The hypsometric equation, which relates height to pressure, was used to obtain hourly variations in true aircraft altitude during C-29A missions. Differences between true and indicated altitude, defined as "altimeter errors," are given, along with statistics on hourly changes in surface temperature and altimeter setting. Finally, a method for calculating altimeter error in flight is provided.

Although the results are only applicable to Scott Air Force Base, Illinois, they can be considered generally representative of other stations with similar field elevations in the midwestern United States. USAFETAC has the ability to produce climatological altimeter error data for any location from which representative upper-air and surface observations are available.



DTIC
COPY
INSPECTED
6

The C-29A (military version of the British Aerospace (BAe) 125 Series 800) was delivered in 1990 for use in the Air Force combat flight inspection mission.

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By _____	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	

CONTENTS

	Page
1. INTRODUCTION.....	1
1.1 Purpose.....	1
1.2 The Problem: Glide Slope Error	1
1.3 Altimeter Settings	1
1.4 The Effects of Using a Constant Altimeter Setting.....	1
1.5 Report Content.....	2
1.6 Application of Results.....	2
2. ALTIMETRY AND ATMOSPHERIC EFFECTS	3
2.1 The Standard Atmosphere.....	3
2.2 Altimeter Setting	3
2.3 The Nonstandard Atmosphere.....	3
2.4 Diurnal Surface Temperature and Altimeter Setting Variations.....	4
2.5 Temperature Inversions.....	4
2.5.1 Radiation Inversions.....	5
2.5.2 Subsidence Inversions.....	6
2.5.3 Frontal Inversions.....	6
2.6 Other Effects	7
3. DATA AND DATA LIMITATIONS.....	8
3.1 Observational Data.....	8
3.2 Data Limitations.....	8
3.3 The Effects of Data Limitations on the Study.....	8
4. METHODOLOGY.....	9
4.1 Procedures	9
4.2 Calculations of Initial Pressure at Flight Level.....	9
4.3 Estimation of Upper-Air Temperature	10
4.3.1 The Dry-Adiabatic Lapse Rate Explained	10
4.3.2 Adjusting the Sounding.....	10
4.5 True Altitude Calculations	11
4.6 Calculations of Altimeter Errors and Other Statistics.....	11
5. RESULTS AND CONCLUSIONS	12
5.1 Statistics	12
5.2 Comments on Statistics	12
5.3 In-Flight Determination of True Altitude	15
6. SUMMARY	16
6.1 The Problem	16
6.2 Review of Basics.....	16
6.3 Method	16
6.4 Results.....	16
6.5 Application.....	16
APPENDIX A Monthly Statistics for 1,000-foot Flight Level, Scott AFB.....	17
APPENDIX B Monthly Statistics for 1,500-foot Flight Level, Scott AFB	21

APPENDIX C	Monthly Statistics for 2,000-foot Flight Level, Scott AFB.....	25
BIBLIOGRAPHY		29
GLOSSARY		30

FIGURES

	Page
Figure 1. ILS Glide Slope Diagram	1
Figure 2. Effects of Nonstandard Temperature on Pressure	3
Figure 3. Mean Daily Scott AFB Surface Temperature and Altimeter Setting for April	4
Figure 4. Vertical Sketch of the Atmosphere from the Surface to the Top of the Troposphere	5
Figure 5. Temperature Lapse Rate Comparisons	5
Figure 6. Idealized Vertical Cross-Section through a Front in the Boundary Layer	6
Figure 7. Same as Figure 6, but with Lines of Constant Pressure Added.....	7
Figure 8. Illustrative Example of the Iterative Process to Adjust the 0600 LST Sounding.....	10
Figure 9. January and July Statistics of Surface Temperature, Altimeter Setting, and Altimeter Error for an 0900-1200 LST C-29A Mission, 1,000-foot Flight Level, Scott AFB, IL.....	13
Figure 10. Same as Figure 9, but for a 1300-1600 LST Mission.....	14

1. INTRODUCTION

1.1 Purpose. The customer (375 MAW/DOM, Scott Air Force Base, Illinois) asked USAFETAC for information on the physical phenomena that cause altimeter errors. As used here, "altimeter error" is defined as the difference between indicated altitude (as shown by the pressure altimeter) and the true altitude. Estimates of the size of this error during a typical 3-hour C-29A mission flown at 1,000, 1,500, and 2,000 feet AGL (above ground level) are given in appendices. Scott AFB surface observations, along with Salem, Illinois, upper-air data, were used in the procedure described by Section 4 to quantify the altimeter errors.

1.2 The Problem: Glide Slope Error. The C-29A, acquired by the Air Force in 1990 to replace the Lockheed C-140 for its worldwide navigational aid (navaid) flight inspection mission, is the military version of the British Aerospace 125-800 twin-engine business jet. During a typical mission, the C-29A uses indicated altitude from a precision pressure altimeter and triangulation to compute the elevation angle of the instrument landing system (ILS) glide slope. Small errors in altitude result in larger errors in the elevation angle. Glide slope width is also measured at 0.35 degrees above and below the glide slope. All measurements are made at fixed indicated altitudes from 1,000 to 2,500 feet AGL. As the aircraft crossed the glide slope horizontally several times, crews found that measurements from the first crossing often differed from those made during subsequent crossings. The problem is to identify the source of these differences; that is, were they caused by atmospheric changes and/or instrument drift, or were they due to calibration errors in the navigation aids?

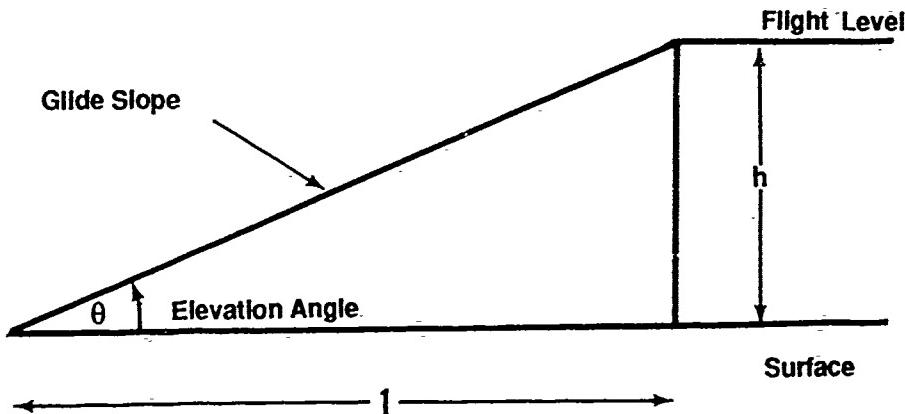


Figure 1. ILS Glide Slope Diagram. During a C-29A flight inspection of the ILS, flight level is assumed constant at a height (h) between 1,000 and 2,500 feet. Elevation angle $\theta = \arctan(h/l)$.

1.3 Altimeter Settings. The C-29A pressure altimeter is set to field elevation before takeoff. Since the position estimation system on the aircraft must be reinitialized whenever the altimeter setting is changed, the initial altimeter setting is used throughout the entire mission unless it changes by 0.03 inches or more.

1.4 The Effects of Using a Constant Altimeter Setting. Typical flight inspection missions are flown from 0900 to 1200 LST (Local Standard Time) and from 1300 to 1600 LST. Because the initial altimeter setting must be maintained throughout the mission (which typically lasts for several hours), indicated altitude will always differ from true altitude because of changes in the atmosphere. Atmospheric pressure is a function of temperature and air density; changes in temperature result in continual changes in actual aircraft altitude.

1.5 Report Content. Section 2 is a review of basic altimetry principles and atmospheric conditions that affect pressure. Section 3 provides a brief discussion of the weather data available for applied studies and the limitations imposed by that data. Section 4 describes the methodology developed to obtain estimates of true altitude changes with time. Results are presented in Section 5. In the appendices, altimeter error estimates are provided for C-29A missions at Scott AFB; for additional information, hourly surface temperature and altimeter changes are included. A procedure for determining true altitude during flight is also provided.

1.6 Application of Results. Since temperature and pressure variations are dependent on climatic region and many local factors, the results given in this study can be applied to the Scott AFB area only. Although the data may be considered generally representative of stations in the midwestern United States with similar field elevations, it is not representative of any other area of the U.S. or of the world.

2. ALTIMETRY AND ATMOSPHERIC EFFECTS.

2.1 The Standard Atmosphere. In the ICAO standard atmosphere, atmospheric pressure at sea level is 29.92 inches or 1013.25 millibars (mb), and the temperature is 15 degrees Celsius (C). Pressure and temperature decrease with altitude upward at a fixed rate. Near the surface, pressure decreases 1 inch for every 1,000-foot increase in elevation; temperature decreases 2 degrees C per 1,000 feet. Precision aircraft altimeters are calibrated to give altitude above sea level in the standard atmosphere based on the atmospheric pressure sensed by the barometer at flight level. Over ocean areas and at 18,000 feet MSL and above, the altimeter is set to 29.92 (standard pressure at sea level); over land and below 18,000 feet, it is set to the currently reported altimeter setting.

2.2 Altimeter Setting. The aircraft altimeter is a pressure-sensing device calibrated to indicate altitude in the standard atmosphere. To make it read correctly, the altimeter is set to a pressure at sea level that would make the instrument indicate zero if it were 10 feet above mean sea level. When the currently reported local altimeter setting is set into the altimeter before takeoff, the instrument should indicate local field elevation.

2.3 The Nonstandard Atmosphere. Because of the dynamic nature of the atmosphere, temperature and height at a given level are usually never "standard." Specifically, this is because of differential heating of the earth's surface and of the atmosphere, and an ever-changing temperature field. The observed rate of change of temperature with height (the temperature lapse rate mentioned in 2.1) is therefore rarely standard. Since temperature is directly proportional to pressure, nonstandard temperatures create pressure deviations at any given height. The effects of nonstandard temperature on pressure are shown in Figure 2. In a standard atmosphere, an aircraft with a correctly set altimeter will fly along a constant pressure surface and maintain a constant height, represented by the dashed line. However, as the pressure surface moves with time, the aircraft will be higher or lower than the altitude shown by the altimeter depending on whether temperature has increased or decreased. For example, if flight level temperature becomes colder than standard, the constant pressure surface is depressed--the aircraft is *lower* than the indicated altitude. Conversely, when flight-level temperature is warmer than standard, the aircraft is *higher* than indicated.

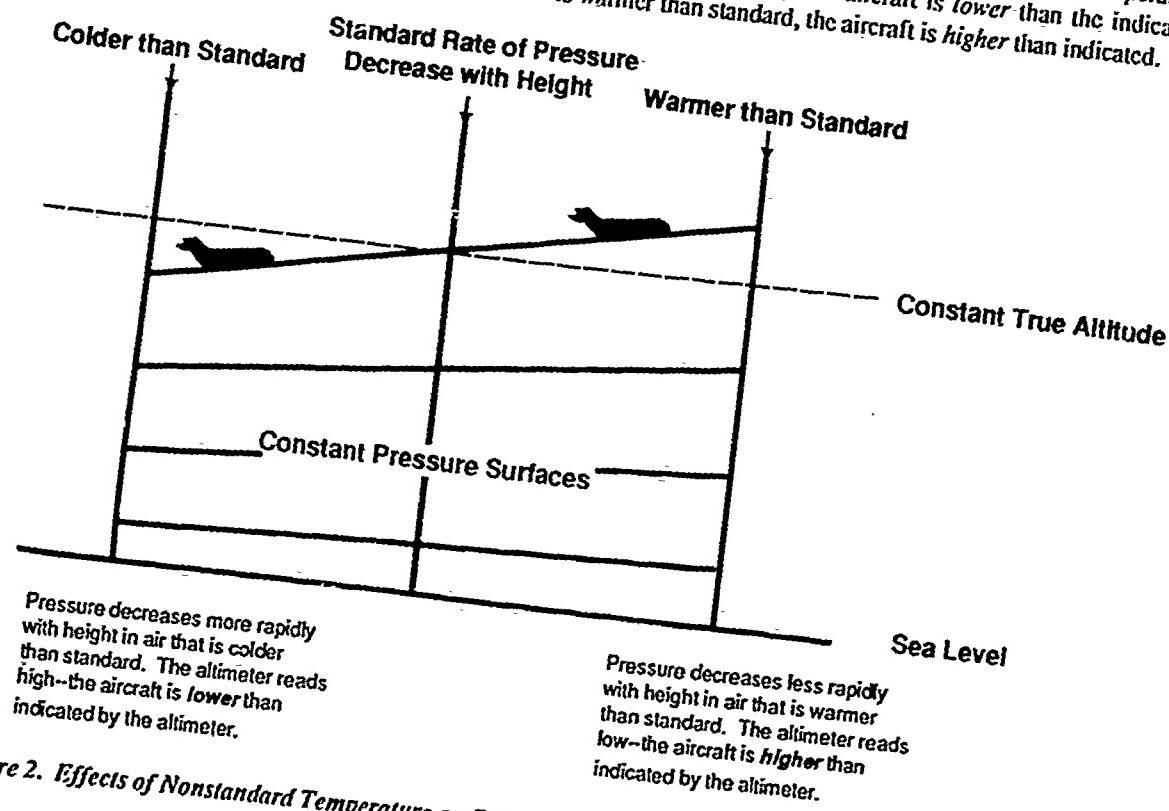


Figure 2. Effects of Nonstandard Temperature on Pressure. Adapted from AFM SI-12, Vol I (1982).

2.4 Diurnal Surface Temperature and Altimeter Setting Variations. Surface temperatures and altimeter settings have diurnal variations; they both have a maximum and a minimum during a normal day. Figure 3 shows plotted mean daily Scott AFB surface temperatures and altimeter settings for April. Note that altimeter setting increases as evening and early morning cooling increases air density and raises pressure near the surface. It falls as late morning and afternoon surface heating decreases the density and lowers pressure. Since the altimeter setting curve represents a line of constant field elevation, it follows that when the altimeter setting increases, the true altitude of an aircraft using that altimeter setting also increases. The opposite is true when the altimeter setting decreases. This is analogous to the situation presented in Figure 2; when the true constant pressure surface is elevated, the aircraft is higher than the indicated altitude, and vice-versa. Since diurnal temperature and pressure variations persist from the surface to several thousand feet, it can be inferred from Figure 3 that, on the average, C-29A morning missions will be at true altitudes *higher* than indicated altitudes, and that afternoon missions will be at true altitudes *lower* than indicated altitudes. The results discussed in Section 5 show that this is, in fact, the case.

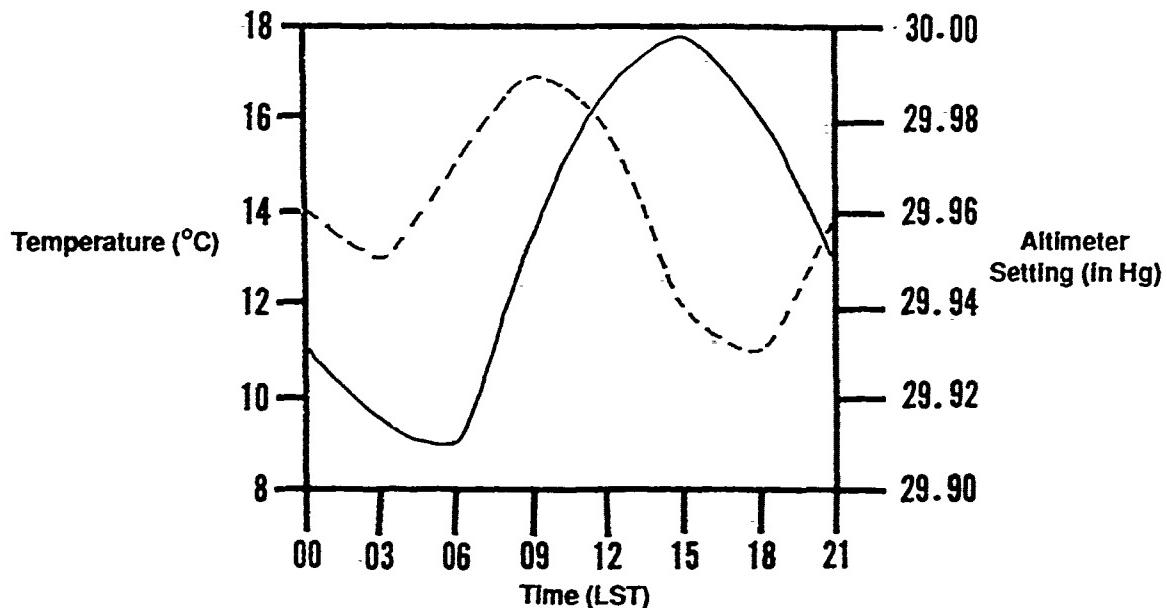


Figure 3. Mean Daily Scott AFB Surface Temperature and Altimeter Setting for April. Period of Record: 1973-1988. Temperature is represented by the solid line; altimeter setting, by the dashed line.

2.5 Temperature Inversions. There are often layers in the atmosphere in which the temperature *increases* with height rather than decreasing as in the standard atmosphere. These layers, called "temperature inversions," may occur anywhere in the atmosphere. A vertical sketch of the atmosphere through the troposphere (from surface to about 36,000 feet) is shown in Figure 4. In this report, the discussion of inversions is limited to the lowest 3,000 feet of the atmosphere, a region known as the "planetary boundary layer," and hereafter referred to simply as the "boundary layer." Although there are several situations in which temperature inversions develop, only the most common ones are described here. The important things to remember are that inversions cause departures from standard temperature lapse rates in the boundary layer, and that these changes affect the true altitude of an aircraft flying through the boundary layer.

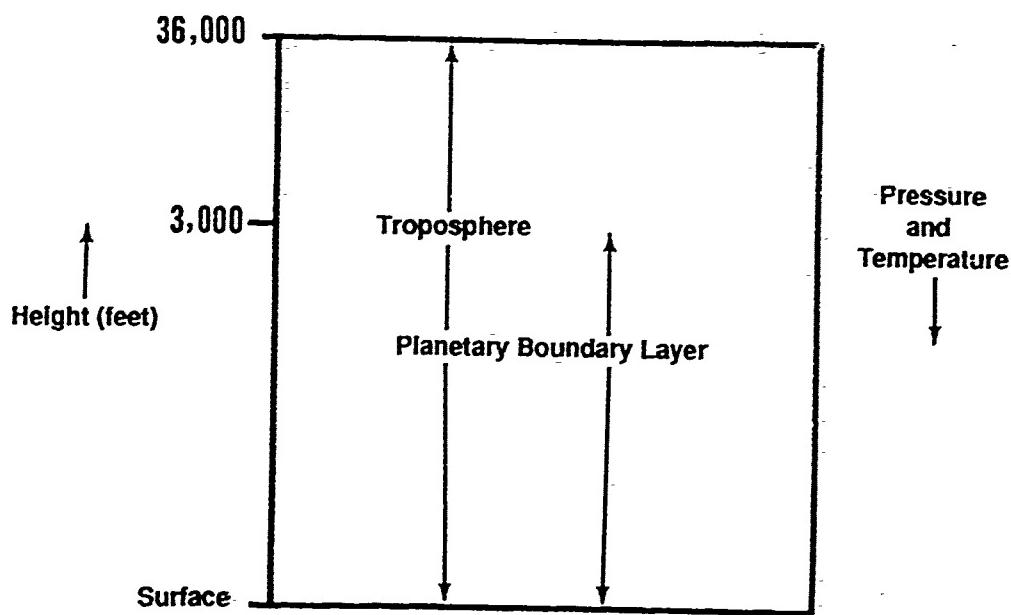


Figure 4. Vertical Sketch of the Atmosphere from the Surface to the Top of the Troposphere.

2.5.1 Radiation Inversions. A common temperature inversion in the boundary layer is the "radiation inversion." It generally forms at night, when skies are clear and winds are light. As the earth transmits long-wave radiation back into space, the earth's surface cools rapidly, also cooling the air close to the surface. At the point where surface cooling has little effect on the atmosphere, there is a sharp return to the prevailing lapse rate. The layer in which this sharp return occurs (the inversion layer) is marked by increased temperature with height. Radiation inversions are usually shallow; they dissipate during mid-morning when the sun heats the surface and breaks the shallow, cooled layer next to the surface. As dissipation of the inversion proceeds, the lapse rate in the lower boundary layer tends back toward standard. In the afternoon on fair weather days with little or no clouds, due to solar heating, the lapse rate exceeds the standard. Figure 5 shows the temperature lapse rate in an early morning inversion layer (segment BC), the standard lapse rate (segment AD), and the afternoon lapse rate (segment AE).

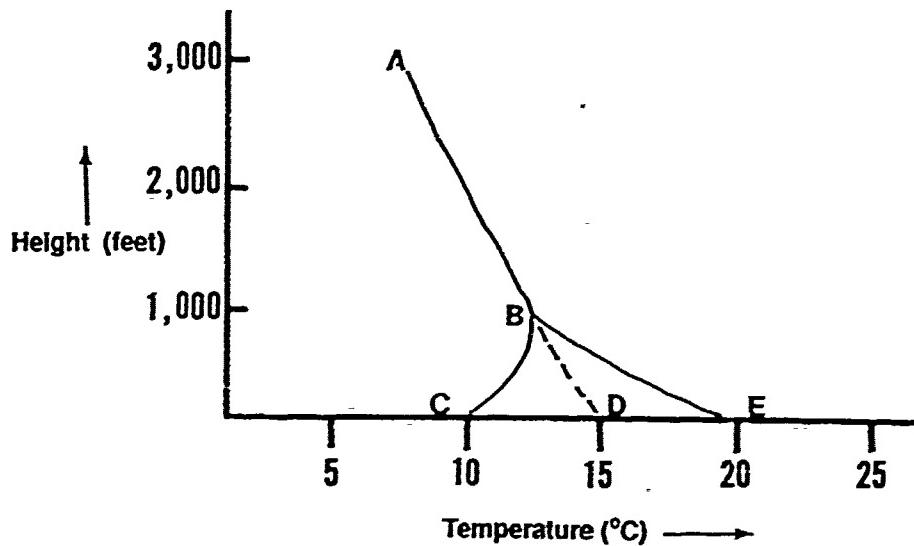


Figure 5. Temperature Lapse Rate Comparisons. The early morning inversion lapse rate is shown in segment BC, the standard lapse rate in segment AD, and the afternoon lapse rate in segment AE.

2.5.2 Subsidence Inversions. Another type of inversion that can influence the temperature lapse rate near the surface is the subsidence inversion, which forms when a large area falls under the influence of high pressure and fair weather. Under these conditions, air aloft sinks, or "subsides." As it does, the subsiding air is heated by compression, creating a layer of warm air--the inversion. When a subsidence inversion penetrates the boundary layer, it may strengthen an existing radiation inversion and result in stagnant air for a period of several days. The result is haze, with visibilities reduced to 3-5 miles. In extreme cases, the entire depth of the boundary layer is characterized by increasing temperature with height. Examples are the well-known winter inversions in Salt Lake City and the summer inversions in Los Angeles.

2.5.3 Frontal Inversions. The term "front" is used in meteorology to describe the leading edge of an air mass whose temperature and density values are different than the air mass it is replacing or overrunning. There are four types of fronts: cold, warm, stationary, and occluded. When a cold air mass advances and replaces warmer air, its leading edge is the cold front. When warm air replaces colder air, the leading edge is a warm front. When a cold air mass and a warm air mass oppose each other with little or no movement on either side, the front is called "stationary." The "occluded front" develops when a cold front overtakes a warm front and forces the warmer air aloft. Frontal inversions develop when warmer air lies over cooler and denser air. As an example, Figure 6 shows an idealized, vertical cross-section through a front in the boundary layer. The base of the temperature inversion is where the temperature lapse rate (the dashed line) intersects the front. The top of the inversion varies depending on the vertical extent of the warm air mass. Figure 7 shows the same cross-section, but with lines of constant pressure added to demonstrate the effects of changing vertical temperature on pressure.

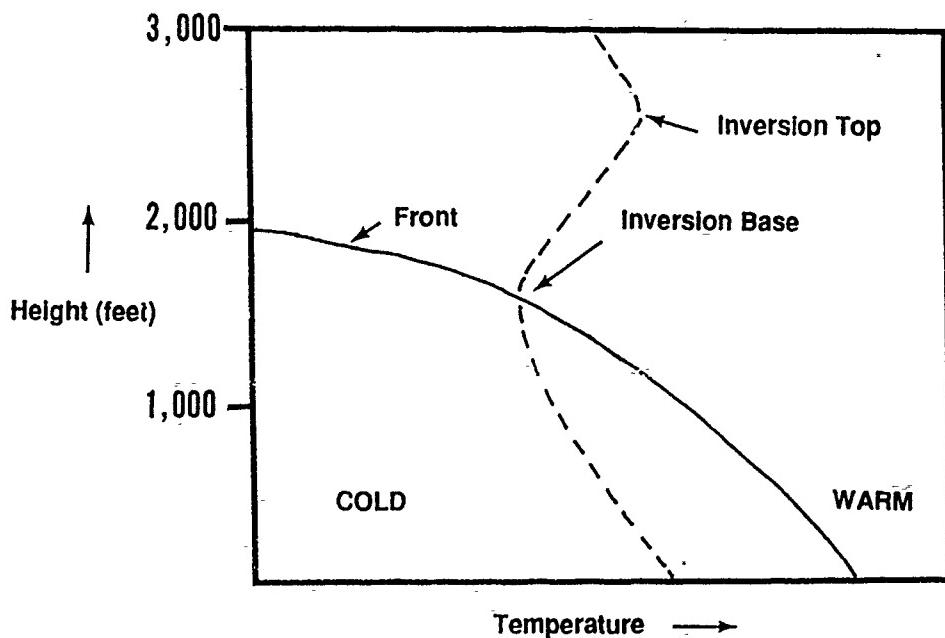


Figure 6. Idealized Vertical Cross-Section through a Front in the Boundary Layer. The top and bottom of the frontal inversion is shown in the temperature lapse rate (dashed line).

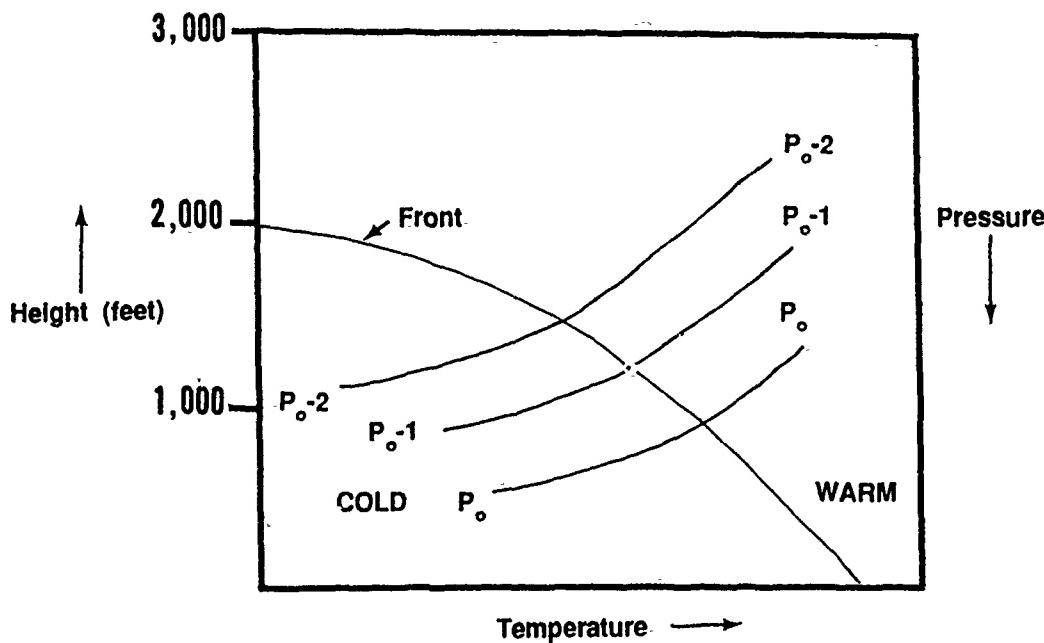


Figure 7. Same as Figure 6, but with Lines of Constant Pressure Added.

2.6 Other Effects. In addition to the phenomena already mentioned, there are other conditions that can change atmospheric pressure. For example, a passing afternoon rain shower can cool the boundary layer when some of the raindrops evaporate. The shower can also transport cooler air downward from above. The result is temporarily higher pressure until the temperature lapse rate readjusts. Rapid formation of thunderstorms, even several miles from the airfield, can lower pressure in the boundary layer by causing a mass deficit when low-level air is drawn into the storm. These two examples of small-scale localized phenomena that can affect pressure lead us to the next section on data and limitations in the current observing network.

3. DATA AND DATA LIMITATIONS:

3.1 Observational Data. Surface observations are available from virtually every major airfield, as well as from many other locations. The upper-air observing network, on the other hand, is much less dense across the United States--upper-air reporting stations are 300 to 500 nautical miles apart.

3.2 Data Limitations. Although surface observations are made at least hourly, upper-air observations are only made twice a day; typically, at 0000 and 1200Z. With only two vertical soundings a day, it's easy to see that changes in temperature and pressure in the boundary layer over a given location can go undetected between soundings. As a rule, the smaller the phenomenon and the shorter its duration, the more likely it will escape detection. Unfortunately, most inversions, fronts, and rainshowers fall into this category.

3.3 The Effects of Data Limitations on the Study. For the purposes of this study, hourly surface weather observations for Scott Air Force Base ($38^{\circ} 33' N$, $89^{\circ} 51' W$, field elevation 453 feet) were sufficient to describe changes of pressure and temperature with time. To describe the vertical temperature structure of the boundary layer over Scott, we used upper-air observations from Salem, Illinois ($38^{\circ} 39' N$, $88^{\circ} 58' W$, elevation 571 feet), a station 41 miles east-northeast of Scott. Since sounding times were 12 hours apart, we used a technique for estimating hourly upper-air temperatures; it is described in Section 4. Because of data limitations and the fact that this study provides a climatology, or history, over a considerable period, it was not possible to isolate the effects of individual inversions, fronts, and other phenomena.

4. METHODOLOGY.

4.1 Procedures. To obtain representative values of altimeter errors for Scott AFB, we used hourly surface weather data (temperature, dew-point temperature, station pressure, and altimeter setting) for Scott and 1200Z upper-air data (temperature and dew point) from Salem. The period of record was January 1973 through December 1988. The upper-air data was interpolated to 100-foot intervals up to 3,000 feet AGL to provide maximum vertical resolution for calculating mean temperatures for several layers from surface to flight level. Conventional atmospheric pressure, temperature, and height relationships were used to calculate hourly changes in true altitude. The hypsometric equation shown below was used to determine true altitude for each hour of two typical C-29A missions: 0900 to 1200 LST and 1300 to 1600 LST. The hypsometric equation is given by

$$z_2 - z_1 = \frac{RT}{g(\ln p_1 - \ln p_2)} \quad (1)$$

where

- z_2 = height of top of layer (meters)
- z_1 = height of bottom of layer (meters)
- T = mean temperature of the layer (K)
- p_1 = pressure at bottom of layer (mb)
- p_2 = pressure at top of layer (mb)
- R = gas constant for dry air ($\text{m}^2/\text{sec}^2/\text{K}$)
- g = acceleration due to gravity (m/sec^2)

The altimeter error was calculated as the difference between true and indicated altitude (initial flight level 1,000, 1,500, and 2,000 feet). For additional information, calculations of hourly surface temperature and altimeter changes were included.

4.2 Calculations of Initial Pressure at Flight Level. Before actual calculations of altimeter error, it was necessary to determine initial pressure at the three requested flight levels (1,000, 1,500, and 2,000 feet). The initial pressure level attained after takeoff and held constant throughout the mission was determined from Equation 1, rewritten as follows:

$$p_{ac} = p_{sfc} e^{\left(\frac{-gh}{TR}\right)} \quad (2)$$

where

- p_{ac} = constant pressure level aircraft is flying (mb)
- p_{sfc} = surface pressure (mb)
- g = acceleration due to gravity (9.8 m/sec^2)
- h = height of aircraft above ground (meters)
- T = mean temperature of the layer from the ground to flight level (K)
- R = gas constant for dry air ($287 \text{ m}^2/\text{sec}^2/\text{K}$)

To obtain T for the layer from surface to flight level for use in Equation 2, the standard lapse rate (-0.0065°C/m) was assumed, and \bar{T} was obtained from

$$\bar{T} = T_{sfc} - .0035h \quad (3)$$

where T_{sfc} is the observed surface temperature kelvin.

4.3 Estimation of Upper-Air Temperature. The procedure described in 4.2 gave values of the initial pressure level (p_{ac}) for three predetermined initial flight levels (indicated altitudes) under standard atmospheric conditions.

To calculate true altitude for the initial takeoff times and for each hour of the mission, the upper-air temperature data was used to determine the mean layer temperature. For greater accuracy, and since virtual temperature accounts for an atmosphere with moisture, the upper-air dew-point temperatures were used to convert upper-air temperatures to virtual temperature.

4.3.1 The Dry Adiabatic Lapse Rate Explained. To obtain values of mean virtual temperature for each hour of a mission, we used a procedure to estimate upper-air temperatures for the hours following the upper-air observation time (0600 LST). To explain that procedure, we have to introduce the concept of the dry-adiabatic lapse rate. In an adiabatic process, there is no heat exchange between an air parcel and its environment. Assuming that the vertical variation of temperature in a dry atmosphere equals the variation of the temperature of a dry air parcel that is expanded adiabatically starting from the same initial point, the dry-adiabatic lapse rate is equal to $-0.0098^{\circ}\text{C}/\text{meter}$. In this study, the initial point for an air parcel is the surface, and its temperature is the observed hourly surface temperature for Scott AFB. The rationale for using this method is this: As the earth's surface is heated during the day, temperatures in the lower portions of the atmosphere, as a whole, decrease with height at the dry-adiabatic lapse rate.

4.3.2 Adjusting the Sounding. As an example, for an 0900 LST takeoff at Scott, the 0900 LST surface temperature is decreased dry-adiabatically. If the dry-adiabatic temperature for a level is warmer than the temperature observed on the 1200Z (0600 LST) sounding, then that temperature is used in calculating the mean. Otherwise, the observed upper-air temperature is used. The sounding is effectively adjusted. Temperatures are estimated at the 100-foot levels between the surface and the point at which the dry-adiabatic lapse rate intersects the original sounding. The portion of the sounding above the intersection point is assumed to be unchanged. The iterative process is demonstrated in Figure 8. The temperatures were used to determine the mean virtual temperature in the atmospheric layer between the surface and the aircraft by averaging the mean virtual temperatures in each 100-foot layer from the surface to the aircraft's constant p_{ac} surface.

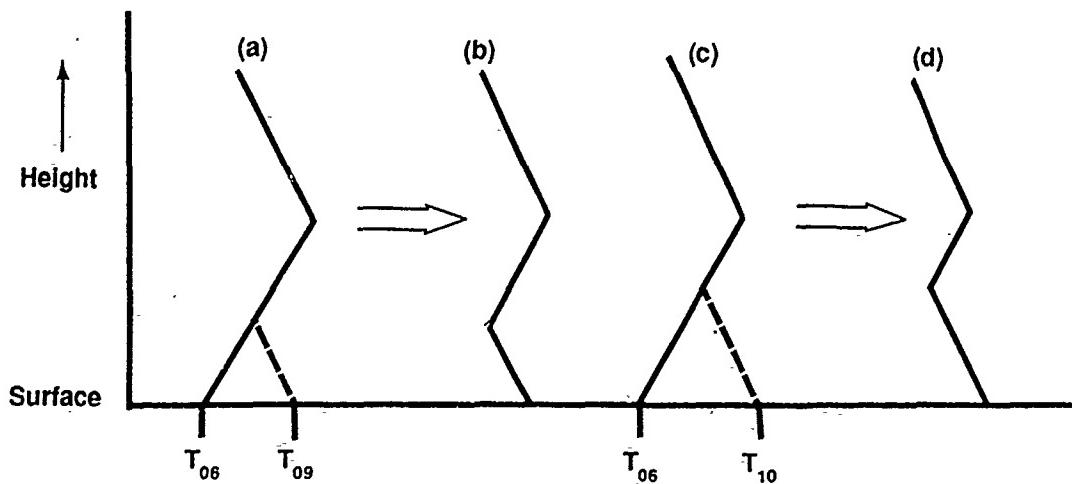


Figure 8. Illustrative Example of the Iterative Process to Adjust the 0600 LST Sounding. In (a), the 0600 LST surface temperature (T_{06}) is replaced by the 0900 LST surface temperature (T_{09}) which is decreased dry-adiabatically (dashed line) until it intersects the original sounding. The resultant sounding adjusted for 0900 LST is shown in (b). The process is repeated in (c) using the 1000 LST surface temperature (T_{10}) to obtain the sounding adjusted for 1000 LST shown in (d).

4.4 True Altitude Calculations. Since the initial altimeter setting is necessarily held constant during C-29A missions, the aircraft's true altitude and indicated altitude will differ due to nonstandard atmospheric conditions. The aircraft will, however, remain at the same pressure level. To obtain an estimate of true aircraft altitude for each hour of a mission, Equation 1 was used, as follows:

$$h_{ac} = \left(\frac{R \bar{T}_v}{g} \right) \ln \left(\frac{p_{sfc}}{p_{ac}} \right) \quad (4)$$

where

h_{ac} = true altitude (meters)

\bar{T}_v = mean virtual temperature of the layer (K) from surface to flight level

4.5 Calculations of Altimeter Errors and Other Statistics. The altimeter error for each hour of a mission was calculated as the difference between true altitude and indicated altitude. The mean and maximum errors were calculated for all months for each of three flight levels: 1,000, 1,500, and 2,000 feet. Absolute values of the mean errors were determined to show the net overall errors with negative values treated as if they were positive. Also, absolute values of the maximum errors were determined. If the absolute maximum error value exceeded that of a particular maximum error value, the absolute maximum error was negative. Similar statistics were calculated for hourly temperature and altimeter changes as additional information for the customer.

5. RESULTS AND CONCLUSIONS

5.1. Statistics. Monthly statistics for Scott AFB (based on a January 1973 through December 1988 period of record) for C-29A mission times of 0900-1200 LST and 1300-1600 LST, are given in the appendices. Mean, maximum, absolute mean, and absolute maximum values of the following variables are given:

TEMPCHG Hourly changes (current temperature minus takeoff temperature) in °C.

TEMPABS Absolute values of hourly temperature changes in °C.

ALSTGCHG Hourly changes (current altimeter minus takeoff altimeter) in 100ths of inches of mercury.

ALSTGABS Absolute values of hourly altimeter changes in 100ths of inches of mercury.

HGTERROR Hourly altimeter errors (true altitude minus indicated altitude) in feet.

HGTERABS Absolute values of hourly altimeter errors in feet.

Statistics for flight levels (indicated altitudes) of 1,000, 1,500, and 2,000 feet are given in Appendices A, B, and C, respectively.

5.2 Comments on Statistics. By way of data interpretation, Figures 9 and 10 show statistics for a 1,000-foot flight level for January and July 0900-1200 LST and 1300-1600 LST missions, respectively. January was chosen because it represents the climatologically coldest month for Scott AFB, while July represents the warmest month. Furthermore, January has more temperature variation in the lower atmosphere due to frontal activity than July. Generally speaking, the most drastic altimeter errors occur in the colder months.

5.2.1 Before discussing the figures, it is important to note that all absolute mean values are greater than the mean values because the calculation of absolute mean values treats observed negative values as positive. Also, all maximum values represent the largest positive values observed. But some negative values did occur. For example, given a maximum altimeter setting of 0.13 inch, a negative value as low as -0.13 would not be shown. However, if the absolute maximum value exceeds the maximum value, it means that a negative value greater than the largest positive value had occurred. As an example, if a maximum altimeter error of 81.5 feet is shown along with an absolute maximum error of 153.4 feet, it means that the extreme errors ranged from 81.5 feet above the indicated altitude to 153.4 feet below.

5.2.2 In Figure 9, the temperature change statistics for each month are similar, reflecting an orderly increase in morning temperatures. The mean altimeter setting changes for each month are similar, but the January maximums far exceed those for July; e.g., maximum and absolute maximum altimeter changes of 0.25 inches by 1200 LST in January versus .06 and .18 inches for the same time in July. Mean altimeter errors are also more erratic in January than in July. January maximum altimeter errors far exceed those for July; the maximum is 251 feet by 1200 LST in January compared to a maximum error of 81.5 feet by the same time in July. The absolute values of mean and maximum altimeter errors are also greater in January than in July.

5.2.3 For an afternoon mission, Figure 10 shows that the temperature change statistics are again similar for each month. The mean altimeter setting changes are negative, since altimeter setting values decrease during the afternoon. Larger negative changes occur in July because of the warmer temperatures. Mean altimeter errors, although negative in both months, are larger in July--again due to warmer temperatures. As with morning missions, the January maximum values of altimeter setting changes exceed those for July; e.g., maximum and absolute maximum altimeter changes of 0.32 inches by 1600 LST in January vs. 0.15 inches in July. Also, the January maximum and absolute maximum values of altimeter errors are almost double those for July.

Month	Hour (LST)	TEMPCHG		TEMPABS		ALSTGCHG		ALSTGABS		HGTERRES	
		Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max
JAN	0900	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	47.5
	1000	1.0	4.9	1.1	6.7	0.9	13.0	1.8	13.0	15.1	139.4
	1100	2.0	7.2	2.1	7.8	0.2	20.0	2.8	20.0	11.8	204.6
	1200	2.8	9.4	3.0	9.4	-2.4	25.0	4.6	25.0	-8.2	251.0
	"	"	"	"	"	"	"	"	"	35.5	251.0
	0900	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	25.3
JUL	1000	1.3	3.9	1.4	3.9	0.0	4.0	0.7	7.0	12.5	59.3
	1100	2.3	6.7	2.4	6.7	-0.5	6.0	1.3	9.0	11.4	77.6
	1200	3.1	7.8	3.2	8.8	-1.6	6.0	2.1	18.0	3.1	81.5
	"	"	"	"	"	"	"	"	"	15.0	153.4
	"	"	"	"	"	"	"	"	"	"	"

TEMPCHG Hourly changes (current temperature minus takeoff temperature) in °C.

TEMPABS Absolute values of hourly temperature changes in °C.

ALSTGCHG Hourly changes (current altimeter minus takeoff altimeter) in inches or millimeters.

ALSTGABS Absolute values of hourly altimeter changes in 100ths of inches or millimeters.

HGTEROR Hourly altimeter errors (true altitude minus indicated altitude) in feet.

HGTERRES Absolute values of hourly altimeter errors in feet.

Figure 9. January and July Statistics of Surface Temperature, Altimeter Setting, and Altimeter Error for an 0900-1200 LST C-29A Mission, 1,000-foot Flight Level, Scott AFB, IL

Month	Hour (LST)	TEMPCHG		TEMPABS		ALSTGCHG		ALSTGABS		HGTERRO		HGTERABS	
		Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max
JAN	1300	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	49.2	3.0	49.2
	1400	-0.4	2.3	0.6	4.5	-1.3	13.0	2.0	13.0	-7.0	128.3	17.2	128.3
	1500	0.6	4.3	1.0	6.2	-1.4	24.0	3.2	24.0	-7.5	227.5	27.9	227.5
	1600	0.4	5.4	1.1	6.7	-0.9	32.0	4.3	32.0	-3.7	299.4	37.6	299.4
JUL	1300	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	25.0	8.0	25.0
	1400	0.3	6.7	0.7	8.9	-1.3	5.0	1.5	10.0	-4.1	46.9	9.0	86.4
	1500	0.4	8.4	1.1	9.4	-2.5	10.0	2.6	14.0	-15.3	98.0	18.2	124.7
	1600	0.1	7.8	1.3	11.6	-3.4	15.0	3.7	15.0	-25.4	141.9	28.3	141.9

TEMPCHG Hourly changes (current temperature minus takeoff temperature) in $^{\circ}\text{C}$.
 TEMPABS Absolute values of hourly temperature changes in $^{\circ}\text{C}$.
 ALSTGCHG Hourly changes (current altimeter minus takeoff altimeter) in 100ths of inches of Mercury.
 ALSTGABS Absolute values of hourly altimeter changes in 100ths of inches of Mercury.
 HGTERRO Hourly altimeter errors (true altitude minus indicated altitude) in feet.
 HGTERABS Absolute values of hourly altimeter errors in feet.

Figure 10. Same as Figure 9, but for a 1300-1600 LST Mission

5.2.4 In comparing the altimeter error information given by these figures, the following general statements about mean and extreme altimeter errors can be made about a typical C-29A mission at Scott AFB at 1,000 feet:

- During morning missions, mean altimeter errors are normally about 15 feet, dropping to near zero or about -10 feet later in the mission. Extreme altimeter errors of more than ± 200 feet are possible in colder months, with errors of more than ± 50 feet likely in the warmer months.
- During afternoon missions, mean altimeter errors just after takeoff are normally about 5 to 10 feet, decreasing to about -10 feet later in the mission in colder months, and to about -25 feet in the warmer months. Extreme altimeter errors approaching ± 300 feet are possible in colder months, with errors of more than ± 100 feet likely in warmer months.
- Inspection of altimeter error statistics for flight levels of 1,500 and 2,000 feet showed that mean altimeter errors increase with higher flight levels on morning and afternoon missions in all months. The increases are small (less than 5 percent), and increases of extreme errors are only slight.

5.3 In-Flight Determination of True Altitude. C-29A crews can use an abbreviated version of the method shown in Section 4 to estimate the altimeter error at any time during a mission. Upon reaching working flight level, the constant pressure level is obtained from Equations 2 and 3. During the mission, Equation 4 is used to estimate true altitude. As input to Equation 4, T_s is approximated by taking the average of the current surface temperature (K) and the observed outside air temperature (K) at flight level. p_{sc} is the observed surface pressure (mb). The altimeter error is obtained by subtracting indicated altitude from true altitude.

6. SUMMARY

6.1 The Problem. This study addressed the problem of altimeter errors (deviations of indicated from true altitude) experienced by C-29A crews during flight inspection missions. Since these missions are flown with a constant altimeter setting, atmospheric changes affect true altitude and result in glide slope elevation angle and width errors.

6.2 Review of Basics. Basic altimetry principles were discussed, including the effects of nonstandard atmospheric temperature and pressure conditions on true aircraft altitude. As examples of atmospheric phenomena that cause temperature and pressure variations, temperature inversions and fronts were described. Some examples of small-scale, short-lived phenomena that cause pressure changes were given, followed by a section on weather data limitations in the upper-air observing network.

6.3 Method. To obtain estimates of the altimeter error, surface temperature, dew-point temperature, and station pressure for Scott AFB were merged with upper-air temperature and dew-point data for Salem, Illinois (period of record January 1973-December 1988) and used as input to the hypsometric equation. Monthly statistics on altimeter errors were calculated for morning and afternoon C-29A missions at flight levels of 1,000, 1,500, and 2,000 feet. Statistics were also included on hourly surface temperature and altimeter changes.

6.4 Results. The study showed that the mean altimeter error over Scott AFB at flight level 1,000 feet was similar for morning missions in both cold and warm months, ranging from a value of 15 feet early in the mission to -10 feet at the end of the mission. Extreme altimeter errors for morning missions were in excess of ± 200 feet for the cold months, and more than ± 50 feet for the warm months. For afternoon missions, the mean altimeter error for cold and warm months was 5 to 10 feet early in the mission, dropping to -10 feet in cold months and -25 feet in warm months. The extreme altimeter errors were larger for afternoon missions, approaching ± 300 feet in the cold months and more than ± 100 feet in the warm months. For all months, the altimeter error statistics for flight levels 1,500 and 2,000 feet showed that mean errors increased by less than 5 percent at higher levels for morning and afternoon missions. Extreme altimeter errors increased only slightly at higher flight levels.

6.5. Application. The results given in this study only apply to Scott AFB, IL. Although they may be considered generally representative of locations with similar field elevations in the midwestern United States, they are not representative of any other locations. USAFETAC has the capability to produce more studies like this one, provided sufficient observational data is available.

APPENDIX A FLIGHT LEVEL 1,000 FEET

TEMPCHG CURRENT MINUS TAKEOFF TEMPERATURE IN C
 TEMPABS ABSOLUTE VALUE OF THE TEMPERATURE CHANGE IN C
 ALSTGCHG CURRENT MINUS TAKEOFF ALTIMETER (100TH IN HG)
 ALSTGABS ABSOLUTE VALUE OF ALSTG CHANGE (100TH IN HG)
 HGTEROR TRUE MINUS INDICATED ALTITUDE IN FEET
 HGTERABS ABSOLUTE VALUE OF ALTITUDE ERROR IN FEET

MO	HR	TEMPCHG		TEMPABS		ALSTGCHG		ALSTGABS		HGTEROR		HGTERABS	
		MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX
JAN	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	47.5	5.0	47.5
	16	1.0	4.9	1.1	6.7	0.9	13.0	1.8	13.0	15.1	139.4	19.8	139.4
	17	2.0	7.2	2.1	7.8	0.2	20.0	2.8	20.0	11.8	204.6	26.4	204.6
	18	2.8	9.4	3.0	9.4	-2.4	25.0	4.6	25.0	-8.2	251.0	35.5	251.0
FEB	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	43.2	6.0	43.2
	16	1.2	5.0	1.3	5.0	0.3	7.0	1.3	8.0	11.7	74.4	16.0	74.4
	17	2.4	8.9	2.5	8.9	0.3	13.0	2.4	13.0	14.8	122.4	23.9	122.4
	18	3.3	12.3	3.4	12.3	-1.3	17.0	3.7	17.0	4.0	158.1	29.9	158.1
MAR	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	37.5	4.5	37.5
	16	1.2	6.7	1.3	6.7	0.2	7.0	1.5	7.0	10.5	88.1	16.0	88.1
	17	2.3	9.4	2.4	9.4	-0.4	10.0	2.8	12.0	8.0	124.8	24.7	124.8
	18	3.2	12.8	3.4	12.8	-1.7	14.0	4.2	19.0	-0.9	161.4	34.2	161.4
APR	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	41.7	4.6	41.7
	16	1.3	4.5	1.4	4.5	0.4	12.0	1.4	12.0	12.0	108.4	16.2	108.4
	17	2.3	8.9	2.4	8.9	-0.3	12.0	2.4	12.0	9.0	113.0	22.1	113.0
	18	3.2	11.7	3.3	11.7	-1.7	12.0	3.8	17.0	-1.1	131.3	30.2	131.3
MAY	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5	30.0	5.5	30.0
	16	1.2	3.9	1.3	6.1	-0.2	5.0	1.0	10.0	7.6	58.5	12.1	87.1
	17	2.2	6.7	2.3	6.7	-0.8	10.0	1.8	11.0	5.5	104.1	16.1	104.1
	18	2.9	8.4	3.1	8.4	-1.9	14.0	3.0	14.0	-2.8	141.3	22.3	141.3
JUN	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1	36.2	7.1	36.2
	16	1.1	3.9	1.3	5.6	-0.0	6.0	0.9	7.0	10.6	74.6	12.9	74.6
	17	2.1	6.1	2.2	6.1	-0.5	8.0	1.5	9.0	9.4	103.3	16.2	103.3
	18	2.9	7.3	3.0	7.3	-1.4	14.0	2.4	14.0	3.1	149.7	19.2	149.7

Figure A-1 January-June Statistics for 1,000-foot Flight Level, Scott AFB.
 Takeoff 1500Z (0900L), Landing 1800Z (1200L)

APPENDIX A FLIGHT LEVEL 1,000 FEET

TEMPCHG CURRENT MINUS TAKEOFF TEMPERATURE IN C
 TEMPABS ABSOLUTE VALUE OF THE TEMPERATURE CHANGE IN C
 ALSTGCHG CURRENT MINUS TAKEOFF ALTIMETER (100TH IN HG)
 ALSTGABS ABSOLUTE VALUE OF ALSTG CHANGE (100TH IN HG)
 HGTEROR TRUE MINUS INDICATED ALTITUDE IN FEET
 HGTERABS ABSOLUTE VALUE OF ALTITUDE ERROR IN FEET

MO	HR	TEMPCHG		TEMPABS		ALSTGCHG		ALSTGABS		HGTEROR		HGTERABS	
		MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX
JUL	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	25.3	8.3	25.3
	16	1.3	3.9	1.4	3.9	-0.0	4.0	0.7	7.0	12.5	59.3	13.4	59.3
	17	2.3	6.7	2.4	6.7	-0.5	6.0	1.3	9.0	11.4	77.6	15.9	77.6
	18	3.1	7.8	3.2	8.8	-1.6	6.0	2.1	18.0	3.1	81.5	15.0	153.4
AUG	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.2	25.0	8.2	25.0
	16	1.5	4.5	1.6	4.5	0.1	7.0	0.8	10.0	14.4	70.4	15.6	83.0
	17	2.6	6.1	2.7	6.1	-0.4	7.0	1.3	10.0	12.5	74.5	16.2	79.7
	18	3.4	8.4	3.5	8.4	-1.6	9.0	2.2	11.0	3.3	88.1	15.6	88.1
SEP	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	39.1	7.0	39.1
	16	1.8	5.6	1.8	5.6	-0.1	11.0	0.8	11.0	11.5	114.8	13.3	114.8
	17	3.0	7.2	3.0	7.2	-1.1	10.0	1.7	10.0	6.0	107.5	13.9	107.5
	18	3.9	8.4	4.0	8.4	-2.5	10.0	3.1	11.0	-5.1	109.1	18.7	109.1
OCT	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6	31.2	5.6	31.2
	16	1.8	7.2	1.8	7.2	-0.2	4.0	1.0	4.0	8.8	55.8	11.7	55.8
	17	3.1	10.0	3.2	10.0	-1.1	5.0	2.0	8.0	5.0	63.5	15.5	63.5
	18	4.2	11.5	4.2	11.5	-2.9	8.0	3.6	13.0	-9.0	81.9	23.4	104.6
NOV	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	36.4	5.9	36.4
	16	1.3	5.6	1.5	5.6	0.2	6.0	1.4	7.0	11.1	71.3	16.1	71.3
	17	2.5	8.9	2.6	8.9	-0.8	10.0	2.7	13.0	6.4	105.7	23.3	108.2
	18	3.3	11.1	3.6	11.1	-3.1	14.0	4.6	18.0	-11.6	142.4	33.7	155.2
DEC	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	37.5	5.9	37.5
	16	1.0	5.6	1.2	5.6	0.9	8.0	1.6	8.0	16.1	95.1	19.0	95.1
	17	2.0	8.4	2.2	8.4	-0.1	12.0	2.7	13.0	10.6	131.4	24.2	131.4
	18	2.7	10.0	3.0	10.0	-2.6	14.0	4.6	19.0	-8.7	149.5	34.4	149.5

Figure A-2 July-December Statistics for 1,000-foot Flight Level, Scott AFB.
Takeoff 1500Z (0900L), Landing 1800Z (1200L)

APPENDIX A FLIGHT LEVEL 1,000 FEET

TEMPCHG CURRENT MINUS TAKEOFF TEMPERATURE IN C
 TEMPABS ABSOLUTE VALUE OF THE TEMPERATURE CHANGE IN C
 ALSTGCHG CURRENT MINUS TAKEOFF ALTIMETER (100TH IN HG)
 ALSTGABS ABSOLUTE VALUE OF ALSTG CHANGE (100TH IN HG)
 HGTEROR TRUE MINUS INDICATED ALTITUDE IN FEET
 HGTERABS ABSOLUTE VALUE OF ALTITUDE ERROR IN FEET

MO	HR	TEMPCHG		TEMPABS		ALSTGCHG		ALSTGABS		HGTEROR		HGTERABS	
		MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX
JAN	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	49.2	3.0	49.2
	20	0.4	2.3	0.6	4.5	-1.3	13.0	2.0	13.0	-7.0	128.3	17.2	128.3
	21	0.6	4.3	1.0	6.2	-1.4	24.0	3.2	24.0	-7.5	227.5	27.9	227.5
	22	0.4	5.4	1.1	6.7	-0.9	32.0	4.3	32.0	-3.7	299.4	37.6	299.4
FEB	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	39.9	3.2	39.9
	20	0.5	2.7	0.7	2.8	-1.7	4.0	2.1	10.0	-10.0	64.5	17.5	69.1
	21	0.8	4.4	1.1	4.4	-2.3	11.0	3.5	12.0	-14.7	116.9	28.8	116.9
	22	0.6	5.0	1.3	5.0	-2.3	18.0	4.6	18.0	-15.1	177.8	39.0	177.8
MAR	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	41.7	3.7	41.7
	20	0.5	3.9	0.8	5.6	-1.8	8.0	2.2	8.0	-10.9	98.5	18.2	98.5
	21	0.7	5.6	1.2	8.9	-2.8	16.0	3.9	16.0	-19.6	156.6	32.9	156.6
	22	0.7	7.8	1.4	10.6	-3.3	22.0	5.1	22.0	-24.8	213.5	44.2	213.5
APR	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.9	48.0	3.9	48.0
	20	0.4	2.8	0.7	7.2	-1.5	6.0	1.9	8.0	-8.6	62.9	15.4	71.3
	21	0.6	3.9	1.1	14.4	-2.9	6.0	3.6	17.3	-20.8	86.1	29.9	151.0
	22	0.5	4.5	1.4	15.5	-3.5	12.0	4.8	19.0	-27.0	105.1	41.1	169.3
MAY	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1	31.9	5.1	31.9
	20	0.4	3.3	0.7	3.8	-1.3	5.0	1.6	8.0	-5.8	50.8	12.4	71.9
	21	0.5	6.1	1.1	8.4	-2.7	7.0	3.1	12.0	-18.8	76.8	25.3	111.5
	22	0.3	6.6	1.3	11.7	-3.4	10.0	4.1	12.0	-26.5	95.5	35.1	113.1
JUN	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.9	25.0	6.9	25.0
	20	0.4	5.0	0.8	7.2	-1.4	7.0	1.6	18.0	-5.1	81.3	11.5	155.7
	21	0.5	6.1	1.2	10.6	-2.5	8.0	2.8	18.0	-6.3	97.8	21.6	155.0
	22	0.3	7.8	1.4	15.6	-3.4	10.0	3.8	19.0	-25.6	109.4	31.0	161.8

Figure A-3 January-June Statistics for 1,000-foot Flight Level, Scott AFB.
Takeoff 1900Z (1300L), Landing 2200Z (1600L)

APPENDIX A FLIGHT LEVEL 1,000 FEET

TEMPCHG CURRENT MINUS TAKEOFF TEMPERATURE IN C
 TEMPABS ABSOLUTE VALUE OF THE TEMPERATURE CHANGE IN C
 ALSTGCHG CURRENT MINUS TAKEOFF ALTIMETER (100TH IN HG)
 ALSTGABS ABSOLUTE VALUE OF ALSTG CHANGE (100TH IN HG)
 HGTEROR TRUE MINUS INDICATED ALTITUDE IN FEET
 HGTERABS ABSOLUTE VALUE OF ALTITUDE ERROR IN FEET

MO	HR	TEMPCHG		TEMPABS		ALSTGCHG		ALSTGABS		HGTEROR		HGTERABS	
		MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX
JUL	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	29.0	8.0	29.0
	20	0.3	6.7	0.7	8.9	-1.3	5.0	1.5	10.0	-4.1	46.9	9.0	88.4
	21	0.4	8.4	1.1	9.4	-2.5	10.0	2.6	14.0	-15.3	98.0	18.2	124.7
	22	0.1	7.8	1.3	11.6	-3.4	15.0	3.7	15.0	-25.4	141.9	28.3	141.9
AUG	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.9	22.7	7.9	22.7
	20	0.2	2.3	0.7	9.5	-1.6	6.0	1.7	7.0	-6.6	46.6	10.2	52.5
	21	0.3	5.0	1.0	10.6	-2.9	7.0	3.0	8.0	-19.6	54.6	21.7	73.2
	22	0.0	10.6	1.2	10.6	-3.7	5.0	3.8	11.0	-28.4	51.6	30.4	109.6
SEP	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.4	41.8	6.4	41.8
	20	0.4	3.9	0.7	5.0	-1.6	6.0	1.8	10.0	-8.2	70.5	12.4	91.3
	21	0.4	7.3	1.0	10.6	-2.8	9.0	3.0	9.0	-19.7	112.4	22.9	112.4
	22	0.1	6.7	1.0	8.9	-3.5	12.0	3.8	12.0	-26.6	140.8	30.9	140.8
OCT	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	39.1	4.2	39.1
	20	0.4	6.1	0.7	6.1	-1.4	4.0	1.6	5.0	-7.3	58.4	12.4	58.4
	21	0.5	9.4	1.0	9.4	-1.9	7.0	2.6	10.0	-12.4	87.3	21.0	88.5
	22	0.1	8.8	1.0	8.9	-2.2	10.0	3.3	17.0	-16.0	112.2	29.0	152.8
NOV	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3	46.8	4.3	46.8
	20	0.3	2.7	0.6	8.3	-1.3	6.0	1.9	10.0	-6.5	86.4	16.6	86.4
	21	0.3	3.4	0.8	10.5	-1.7	14.0	3.1	18.0	-9.4	143.4	27.3	156.9
	22	-0.1	3.8	0.9	12.2	-1.4	22.0	3.9	23.0	-7.9	191.1	36.4	199.1
DEC	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1	51.7	4.1	51.7
	20	0.4	2.8	0.6	2.8	-1.1	8.0	1.9	8.0	-4.5	80.3	16.8	80.3
	21	0.4	3.9	0.9	6.7	-1.1	14.0	3.1	14.0	-4.2	152.7	27.5	152.7
	22	-0.0	6.1	1.0	7.8	-0.6	22.0	4.3	22.0	-0.2	224.2	38.9	224.2

**Figure A-4 July-December Statistics for 1,000-foot Flight Level, Scott AFB.
Takeoff 1900Z (1300L), Landing 2200Z (1600L)**

APPENDIX B FLIGHT LEVEL 1,500 FEET

TEMPCHG CURRENT MINUS TAKEOFF TEMPERATURE IN C
 TEMPABS ABSOLUTE VALUE OF THE TEMPERATURE CHANGE IN C
 ALSTGCHG CURRENT MINUS TAKEOFF ALTIMETER (100TH IN HG)
 ALSTGABS ABSOLUTE VALUE OF ALTIMETER CHANGE (100TH IN HG)
 HGTEROR TRUE MINUS INDICATED ALTITUDE IN FEET
 HGTERABS ABSOLUTE VALUE OF ALTITUDE ERROR IN FEET

MO	HR	TEMPCHG			TEMPABS			ALSTGCHG			ALSTGABS			HGTEROR			HGTERABS		
		MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX		
JAN	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1	71.2	9.3	71.2					
	16	1.0	4.9	1.1	6.7	0.9	13.0	1.8	13.0	19.8	149.3	23.3	149.3						
	17	2.0	7.2	2.1	7.8	0.2	20.0	2.8	20.0	17.3	214.3	28.8	214.3						
	18	2.8	9.4	3.0	9.4	-2.4	25.0	4.6	25.0	-1.6	260.8	34.6	260.8						
FEB	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.8	67.1	10.9	67.1						
	16	1.2	5.0	1.3	5.0	0.3	7.0	1.3	8.0	17.1	89.0	20.3	89.0						
	17	2.4	8.9	2.5	8.9	0.3	13.0	2.4	13.0	21.2	130.0	27.6	130.0						
	18	3.3	12.3	3.4	12.3	-1.3	17.0	3.7	17.0	11.5	158.0	31.4	158.0						
MAR	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.3	56.4	7.4	56.4						
	16	1.2	6.7	1.3	6.7	0.2	7.0	1.5	7.0	14.5	106.8	18.3	106.8						
	17	2.3	9.4	2.4	9.4	-0.4	10.0	2.8	12.0	13.4	143.5	26.3	143.5						
	18	3.2	12.8	3.4	12.8	-1.7	14.0	4.2	19.0	6.0	180.0	33.7	180.0						
APR	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.5	63.2	6.6	63.2						
	16	1.3	4.5	1.4	4.5	0.4	12.0	1.4	12.0	15.6	105.6	18.8	105.6						
	17	2.3	8.9	2.4	8.9	-0.3	12.0	2.4	12.0	14.1	124.0	23.8	124.0						
	18	3.2	11.7	3.3	11.7	-1.7	12.0	3.8	17.0	5.5	142.3	29.7	142.3						
MAY	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.4	47.1	7.4	47.1						
	16	1.2	3.9	1.3	6.1	-0.2	5.0	1.0	10.0	11.3	75.6	14.5	82.7						
	17	2.2	6.7	2.3	6.7	-0.8	10.0	1.8	11.0	10.8	109.0	18.3	109.0						
	18	2.9	8.4	3.1	8.4	-1.9	14.0	3.0	14.0	3.7	146.1	22.1	146.1						
JUN	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.6	57.9	9.6	57.9						
	16	1.1	3.9	1.3	5.6	-0.0	6.0	0.9	7.0	14.9	96.3	16.3	96.3						
	17	2.1	6.1	2.2	6.1	-0.5	8.0	1.5	9.0	15.2	125.0	19.5	125.0						
	18	2.9	7.3	3.0	7.3	-1.4	14.0	2.4	14.0	10.2	156.6	20.7	156.6						

Figure B-1 January-June Statistics for 1,500-foot Flight Level, Scott AFB.
Takeoff 1500Z (0900L), Landing 1800Z (1200L)

APPENDIX B FLIGHT LEVEL 1,500 FEET

TEMPCHG CURRENT MINUS TAKEOFF TEMPERATURE IN C
 TEMPABS ABSOLUTE VALUE OF THE TEMPERATURE CHANGE IN C
 ALSTGCHG CURRENT MINUS TAKEOFF ALTIMETER (100TH IN HG)
 ALSTGABS ABSOLUTE VALUE OF ALSTG CHANGE (100TH IN HG)
 HGTEROR TRUE MINUS INDICATED ALTITUDE IN FEET
 HGTERABS ABSOLUTE VALUE OF ALTITUDE ERROR IN FEET

MO	HR	TEMPCHG		TEMPABS		ALSTGCHG		ALSTGABS		HGTEROR		HGTERABS	
		MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX
JUL	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.4	42.2	11.4	42.2
	16	1.3	3.9	1.4	3.9	-0.0	4.0	0.7	7.0	17.4	71.3	17.9	71.3
	17	2.3	6.7	2.4	6.7	-0.5	6.0	1.3	9.0	18.0	84.9	20.8	84.9
	18	3.1	7.8	3.2	8.8	-1.6	6.0	2.1	18.0	11.0	90.8	17.4	145.6
AUG	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.6	38.0	11.6	38.0
	16	1.5	4.5	1.6	4.5	0.1	7.0	0.8	10.0	19.6	74.4	20.3	77.2
	17	2.6	6.1	2.7	6.1	-0.4	7.0	1.3	10.0	19.5	76.2	21.4	76.2
	18	3.4	8.4	3.5	8.4	-1.6	9.0	2.2	11.0	11.6	91.7	18.2	91.7
SEP	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.3	59.0	10.3	59.0
	16	1.8	5.6	1.8	5.6	-0.1	11.0	0.8	11.0	16.9	117.8	17.9	117.8
	17	3.0	7.2	3.0	7.2	-1.1	10.0	1.7	10.0	13.2	111.6	17.4	111.6
	18	3.9	8.4	4.0	8.4	-2.5	10.0	3.1	11.0	3.6	113.5	18.1	113.5
OCT	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.2	47.4	9.2	47.4
	16	1.8	7.2	1.8	7.2	-0.2	4.0	1.0	4.0	13.8	69.6	15.4	69.6
	17	3.1	10.0	3.2	10.0	-1.1	5.0	2.0	8.0	11.9	72.4	18.1	72.4
	18	4.2	11.5	4.2	11.5	-2.9	8.0	3.6	13.0	-0.5	90.9	21.7	97.1
NOV	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	55.6	10.1	55.6
	16	1.3	5.6	1.5	5.6	0.2	6.0	1.4	7.0	16.0	92.6	19.4	92.6
	17	2.5	8.9	2.6	8.9	-0.8	10.0	2.7	13.0	12.6	120.7	25.2	120.7
	18	3.3	11.1	3.6	11.1	-3.1	14.0	4.6	18.0	-4.1	151.6	31.9	153.6
DEC	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.6	59.1	10.8	59.1
	16	1.0	5.6	1.2	5.6	0.9	8.0	1.6	8.0	21.3	113.9	23.3	113.9
	17	2.0	8.4	2.2	8.4	-0.1	12.0	2.7	13.0	16.6	150.7	26.6	150.7
	18	2.7	10.0	3.0	10.0	-2.6	14.0	4.6	19.0	-1.7	169.1	33.2	169.1

**Figure B-2 July-December Statistics for 1,500-foot Flight Level, Scott AFB:
Takeoff 1500Z (0900L), Landing 1800Z (1200L)**

APPENDIX B FLIGHT LEVEL 1,500 FEET

TEMPCHG CURRENT MINUS TAKEOFF TEMPERATURE IN C
 TEMPABS ABSOLUTE VALUE OF THE TEMPERATURE CHANGE IN C
 ALSTGCHG CURRENT MINUS TAKEOFF ALTIMETER (100TH IN HG)
 ALSTGABS ABSOLUTE VALUE OF ALSTG CHANGE (100TH IN HG)
 HGTEROR TRUE MINUS INDICATED ALTITUDE IN FEET
 HGTERABS ABSOLUTE VALUE OF ALTITUDE ERROR IN FEET

MO	HR	TEMPCHG		TEMPABS		ALSTGCHG		ALSTGABS		HGTEROR		HGTERABS	
		MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX
JAN	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	75.3	4.7	75.3
	20	0.4	2.3	0.6	4.5	-1.3	13.0	2.0	13.0	-5.1	138.1	17.7	138.1
	21	0.6	4.3	1.0	6.2	-1.4	24.0	3.2	24.0	-5.2	237.4	28.1	237.4
	22	0.4	5.4	1.1	6.7	-0.9	32.0	4.3	32.0	-1.7	309.3	37.8	309.3
FEB	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3	60.9	4.8	60.9
	20	0.5	2.7	0.7	2.8	-1.7	4.0	2.1	10.0	-8.0	79.8	17.9	87.1
	21	0.8	4.4	1.1	4.4	-2.3	11.0	3.5	12.0	-12.2	132.0	28.5	132.0
	22	0.6	5.0	1.3	5.0	-2.3	18.0	4.6	18.0	-12.6	192.9	38.8	192.9
MAR	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	65.2	4.8	65.2
	20	0.5	3.9	0.8	5.6	-1.8	8.0	2.2	8.0	-8.9	111.0	18.3	111.0
	21	0.7	5.6	1.2	8.9	-2.8	16.0	3.9	16.0	-17.3	158.0	32.5	158.0
	22	0.7	7.8	1.4	10.6	-3.3	22.0	5.1	22.0	-22.5	214.8	43.8	214.8
APR	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8	72.7	4.9	72.7
	20	0.4	2.8	0.7	7.2	-1.5	6.0	1.9	8.0	-7.0	82.2	15.2	82.2
	21	0.6	3.9	1.1	14.4	-2.9	6.0	3.6	17.0	-18.8	110.7	29.0	150.3
	22	0.5	4.5	1.4	15.5	-3.5	12.0	4.8	19.0	-25.0	129.7	40.3	168.5
MAY	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.5	49.9	6.6	49.9
	20	0.4	3.3	0.7	3.8	-1.3	5.0	1.6	8.0	-3.8	68.9	12.5	69.2
	21	0.5	6.1	1.1	8.4	-2.7	7.0	3.1	12.0	-16.5	83.4	24.4	110.5
	22	0.3	6.6	1.3	11.7	-3.4	10.0	4.1	12.0	-24.4	102.0	34.1	117.9
JUN	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1	42.2	9.1	42.2
	20	0.4	5.0	0.8	7.2	-1.4	7.0	1.6	18.0	-2.2	85.6	11.3	146.1
	21	0.5	6.1	1.2	10.6	-2.5	8.0	2.8	18.0	-13.3	109.2	20.2	145.5
	22	0.3	7.8	1.4	15.6	-3.4	10.0	3.8	19.0	-22.7	116.3	29.3	151.8

Figure B-3 January-June Statistics for 1,500-foot Flight Level, Scott AFB.
Takeoff 1900Z (1300L), Landing 2200Z (1600L)

APPENDIX B FLIGHT LEVEL 1,500 FEET

TEMPCHG CURRENT MINUS TAKEOFF TEMPERATURE IN C
 TEMPABS ABSOLUTE VALUE OF THE TEMPERATURE CHANGE IN C
 ALSTGCHG CURRENT MINUS TAKEOFF ALTIMETER (100TH IN HG)
 ALSTGABS ABSOLUTE VALUE OF ALSTG CHANGE (100TH IN HG)
 HGTEROR TRUE MINUS INDICATED ALTITUDE IN FEET
 HGTERABS ABSOLUTE VALUE OF ALTITUDE ERROR IN FEET

	MO	HR	TEMPCHG		TEMPABS		ALSTGCHG		ALSTGABS		HGTEROR		HGTERABS	
			MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX
JUL	19		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.5	48.7	10.5	48.7
	20		0.3	6.7	0.7	8.9	-1.3	5.0	1.5	10.0	-1.0	49.5	9.0	83.8
	21		0.4	8.4	1.1	9.4	-2.5	10.0	2.6	14.0	-12.0	100.7	16.5	118.3
	22		0.1	7.8	1.3	11.6	-3.4	15.0	3.7	15.0	-22.5	145.0	26.1	145.0
AUG	19		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.4	40.5	10.4	40.5
	20		0.2	2.3	0.7	9.5	-1.6	6.0	1.7	7.0	-3.5	59.4	9.6	59.4
	21		0.3	5.0	1.0	10.6	-2.9	7.0	3.0	8.0	-16.4	53.3	19.3	72.0
	22		0.0	10.6	1.2	10.6	-3.7	5.0	3.8	11.0	-25.5	69.5	28.1	115.5
SEP	19		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	63.8	8.3	63.8
	20		0.4	3.9	0.7	5.0	-1.6	6.0	1.8	10.0	-5.7	92.4	11.9	92.4
	21		0.4	7.3	1.0	10.6	-2.8	9.0	3.0	9.0	-17.0	131.6	21.2	131.6
	22		0.1	6.7	1.0	8.9	-3.5	12.0	3.8	12.0	-24.3	160.1	29.4	160.1
OCT	19		0.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	5.2	57.7	5.3	57.7
	20		0.4	6.4	0.7	6.1	-1.4	4.0	1.6	5.0	-5.5	76.9	12.4	76.9
	21		0.5	9.4	1.0	9.4	-1.9	7.0	2.6	10.0	-10.5	105.8	20.5	105.8
	22		0.1	8.8	1.0	8.9	-2.2	10.0	3.3	17.0	-14.6	121.9	28.7	150.4
NOV	19		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6	70.4	5.8	70.4
	20		0.3	2.7	0.6	8.7	1.3	6.0	1.9	10.0	-4.4	106.7	17.1	106.7
	21		0.3	3.4	0.8	10.5	-1.7	14.0	3.1	18.0	-7.2	163.6	27.6	163.6
	22		-0.1	3.8	0.9	12.2	-1.4	22.0	3.9	23.0	-6.4	201.5	37.0	201.5
DEC	19		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	83.8	6.4	83.8
	20		0.4	2.8	0.6	2.8	-1.1	8.0	1.9	8.0	-2.0	107.7	17.8	107.7
	21		0.4	3.9	0.9	6.7	-1.1	14.0	3.1	14.0	-1.5	171.1	28.4	171.1
	22		-0.0	6.1	1.0	7.8	-0.6	22.0	4.3	22.0	2.1	242.6	40.0	242.6

**Figure B-4 July-December Statistics for 1,500-foot Flight Level, Scott AFB.
Takeoff 1900Z (1300L), Landing 2200Z (1600L)**

APPENDIX C FLIGHT LEVEL 2,000 FEET

TEMPCHG CURRENT MINUS TAKEOFF TEMPERATURE IN C
 TEMPABS ABSOLUTE VALUE OF THE TEMPERATURE CHANGE IN C
 ALSTGCHG CURRENT MINUS TAKEOFF ALTIMETER (100TH IN HG)
 ALSTGABS ABSOLUTE VALUE OF ALSTG CHANGE (100TH IN HG)
 HGTEROR TRUE MINUS INDICATED ALTITUDE IN FEET
 HGTERABS ABSOLUTE VALUE OF ALTITUDE ERROR IN FEET

MO	HR	TEMPCHG		TEMPABS		ALSTGCHG		ALSTGABS		HGTEROR		HGTERABS	
		MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX
JAN	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.8	94.6	15.4	94.6
	16	1.0	4.9	1.1	6.7	0.9	13.0	1.8	13.0	25.8	159.2	28.3	159.2
	17	2.0	7.2	2.1	7.8	0.2	20.0	2.8	20.0	23.9	224.2	32.5	224.2
	18	2.8	9.4	3.0	9.4	-2.4	25.0	4.6	25.0	5.8	270.5	35.0	270.5
FEB	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.0	91.5	17.6	91.5
	16	1.2	5.0	1.3	5.0	0.3	7.0	1.3	8.0	23.8	110.0	26.1	110.0
	17	2.4	8.9	2.5	8.9	0.3	13.0	2.4	13.0	28.5	144.1	33.0	144.1
	18	3.3	12.3	3.4	12.3	-1.3	17.0	3.7	17.0	19.7	161.7	34.6	161.7
MAR	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.8	75.0	11.2	75.0
	16	1.2	6.7	1.3	6.7	0.2	7.0	1.5	7.0	18.8	126.4	21.4	126.4
	17	2.3	9.4	2.4	9.4	-0.4	10.0	2.8	12.0	18.8	163.0	28.6	163.0
	18	3.2	12.8	3.4	12.8	-1.7	14.0	4.2	19.0	12.8	199.6	34.6	199.6
APR	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.6	85.2	8.8	85.2
	16	1.3	4.5	1.4	4.5	0.4	12.0	1.4	12.0	19.0	117.0	21.5	117.0
	17	2.3	8.9	2.4	8.9	-0.3	12.0	2.4	12.0	19.0	135.3	26.3	135.3
	18	3.2	11.7	3.3	11.7	-1.7	12.0	3.8	17.0	11.9	153.6	30.6	153.6
MAY	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.8	64.9	8.9	64.9
	16	1.2	3.9	1.3	6.1	-0.2	5.0	1.0	10.0	14.4	93.3	16.9	93.3
	17	2.2	6.7	2.3	6.7	-0.8	10.0	1.8	11.0	15.3	121.7	21.3	121.7
	18	2.9	8.4	3.1	8.4	-1.9	14.0	3.0	14.0	9.4	159.5	23.2	159.5
JUN	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.7	79.9	11.7	79.9
	16	1.1	3.9	1.3	5.6	-0.0	6.0	0.9	7.0	18.5	118.3	19.5	118.3
	17	2.1	6.1	2.2	6.1	-0.5	8.0	1.5	9.0	20.2	147.0	23.3	147.0
	18	2.9	7.3	3.0	7.3	-1.4	14.0	2.4	14.0	16.4	163.6	23.6	163.6

**Figure C-1 January-June Statistics for 2,000-foot Flight Level, Scott AFB.
Takeoff 1300Z (0900L), Landing 1800Z (1200L)**

APPENDIX C FLIGHT LEVEL 2,000 FEET

TEMPCHG CURRENT MINUS TAKEOFF TEMPERATURE IN C
 TEMPABS ABSOLUTE VALUE OF THE TEMPERATURE CHANGE IN C
 ALSTGCHG CURRENT MINUS TAKEOFF ALTIMETER (100TH IN HG)
 ALSTGABS ABSOLUTE VALUE OF ALSTG CHANGE (100TH IN HG)
 HGTEROR TRUE MINUS INDICATED ALTITUDE IN FEET
 HGTERABS ABSOLUTE VALUE OF ALTITUDE ERROR IN FEET

MO	HR	TEMPCHG		TEMPABS		ALSTGCHG		ALSTGABS		HGTEROR		HGTERABS	
		MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX
JUL	15	0.0	0.0	0.01	0.0	0.01	0.0	0.0	0.0	14.1	59.4	14.2	59.4
	16	1.3	3.9	1.4	3.9	-0.0	4.0	0.7	7.0	21.6	83.0	21.9	83.0
	17	2.3	6.7	2.4	6.7	-0.5	6.0	1.3	9.0	23.6	91.0	25.6	91.0
	18	3.1	7.8	3.2	8.8	-1.6	6.0	2.1	18.0	17.9	98.7	21.5	138.2
AUG	15	0.0	0.0	0.01	0.0	0.01	0.0	0.0	0.0	14.9	51.3	14.9	51.3
	16	1.5	4.5	1.6	4.5	0.1	7.0	0.8	10.0	24.2	80.2	24.8	80.2
	17	2.6	6.1	2.7	6.1	-0.4	7.0	1.3	10.0	25.7	77.5	27.0	77.5
	18	3.4	8.4	3.5	8.4	-1.6	9.0	2.2	11.0	19.0	99.8	22.7	99.8
SEP	15	0.0	0.0	0.01	0.0	0.01	0.0	0.0	0.0	13.6	79.1	13.7	79.1
	16	1.8	5.6	1.8	5.6	-0.1	11.0	0.8	11.0	21.7	120.1	22.3	120.1
	17	3.0	7.2	3.0	7.2	-1.1	10.0	1.7	10.0	19.7	114.7	22.2	114.7
	18	3.9	8.4	4.0	8.4	-2.5	10.0	3.1	11.0	11.4	116.8	20.1	116.8
OCT	15	0.0	0.0	0.01	0.0	0.01	0.0	0.0	0.0	13.1	68.0	13.2	68.0
	16	1.8	7.2	1.8	7.2	-0.2	4.0	1.0	4.0	18.8	83.5	19.8	83.5
	17	3.1	10.0	3.2	10.0	-1.1	5.0	2.0	8.0	18.4	84.9	22.2	84.9
	18	4.2	11.5	4.2	11.5	-2.9	8.0	3.6	13.0	7.5	100.1	22.8	100.1
NOV	15	0.0	0.0	0.01	0.0	0.01	0.0	0.0	0.0	15.2	76.8	15.3	76.8
	16	1.3	5.6	1.5	5.6	0.2	6.0	1.4	7.0	21.6	114.3	23.8	114.3
	17	2.5	8.9	2.6	8.9	-0.8	10.0	2.7	13.0	19.0	142.4	28.3	142.4
	18	3.3	11.1	3.6	11.1	-3.1	14.0	4.6	18.0	3.3	164.8	31.6	164.8
DEC	15	0.0	0.0	0.01	0.0	0.01	0.0	0.0	0.0	16.8	85.8	17.4	85.8
	16	1.0	5.6	1.2	5.6	0.9	8.0	1.6	8.0	27.8	135.8	29.1	135.8
	17	2.0	8.4	2.2	8.4	-0.1	12.0	2.7	13.0	23.6	172.5	30.6	172.5
	18	2.7	10.0	3.0	10.0	-2.6	14.0	4.6	19.0	5.9	190.9	33.4	190.9

Figure C-2 July-December Statistics for 2,000-foot Flight Level, Scott AFB,
Takeoff 1500Z (0900L), Landing 1800Z (1200L)

APPENDIX C FLIGHT LEVEL 2,000 FEET

TEMPCHG CURRENT MINUS TAKEOFF TEMPERATURE IN C
TEMPABS ABSOLUTE VALUE OF THE TEMPERATURE CHANGE IN C
ALSTGCHG CURRENT MINUS TAKEOFF ALTIMETER (100TH IN HG)
ALSTGABS ABSOLUTE VALUE OF ALSTG CHANGE (100TH IN HG)
HGTERROR TRUE MINUS INDICATED ALTITUDE IN FEET
HGTERABS ABSOLUTE VALUE OF ALTITUDE ERROR IN FEET

MO	HR	TEMPCHG		TEMPABS		ALSTGCHG		ALSTGABS		HGTERROR		HGTERABS	
		MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX
JAN	19	-0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.3	101.5	7.6	101.5
	20	0.4	2.3	0.6	4.5	-1.3	13.0	2.0	13.0	-3.1	150.8	18.8	150.8
	21	0.6	4.3	1.0	6.2	-1.4	24.0	3.2	24.0	-2.8	250.2	28.5	250.2
	22	0.4	5.4	1.1	6.7	-0.9	32.0	4.3	32.0	0.6	322.2	38.3	322.2
FEB	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.8	83.1	7.6	83.1
	20	0.5	2.7	0.7	2.8	-1.7	4.0	2.1	10.0	-5.8	101.3	19.0	101.3
	21	0.8	4.4	1.1	4.4	-2.3	11.0	3.5	12.0	-9.4	147.5	28.8	147.5
	22	0.6	5.0	1.3	5.0	-2.3	18.0	4.6	18.0	-9.8	208.3	39.1	208.3
MAR	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.4	89.4	6.2	89.4
	20	0.5	3.9	0.8	5.6	-1.8	8.0	2.2	8.0	-7.2	123.9	19.1	123.9
	21	0.7	5.6	1.2	8.9	-2.8	16.0	3.9	16.0	-15.1	158.9	32.7	158.9
	22	0.7	7.8	1.4	10.6	-3.3	22.0	5.1	22.0	-20.4	215.6	44.0	215.6
APR	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1	97.2	5.5	97.2
	20	0.4	2.8	0.7	7.2	-1.5	6.0	1.9	8.0	-5.9	106.7	15.6	106.7
	21	0.6	3.9	1.1	14.4	-2.9	6.0	3.6	17.0	-17.2	135.1	28.7	150.5
	22	0.5	4.5	1.4	15.5	-3.5	12.0	4.8	19.0	-23.4	154.1	39.9	168.7
MAY	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1	68.8	7.3	68.8
	20	0.4	3.3	0.7	3.8	-1.3	5.0	1.6	8.0	-2.6	87.7	13.1	87.7
	21	0.5	6.1	1.1	8.4	-2.7	7.0	3.1	12.0	-14.9	93.8	24.3	110.6
	22	0.3	6.6	1.3	11.7	-3.4	10.0	4.1	12.0	-23.1	109.3	34.0	123.7
JUN	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.4	60.4	10.5	60.4
	20	0.4	5.0	0.8	7.2	-1.4	7.0	1.6	18.0	-0.2	88.9	11.9	136.4
	21	0.5	6.1	1.2	10.6	-2.5	8.0	2.8	18.0	-11.0	120.6	19.9	135.8
	22	0.3	7.8	1.4	15.6	-3.4	10.0	3.8	19.0	-20.6	123.1	28.5	142.1

**Figure C-3 January-June Statistics for 2,000-foot Flight Level, Scott AFB.
Takeoff 1900Z (1300L), Landing 2200Z (1600L)**

APPENDIX C FLIGHT LEVEL: 2,000 FEET

TEMPCHG CURRENT MINUS TAKEOFF TEMPERATURE IN C
 TEMPABS ABSOLUTE VALUE OF THE TEMPERATURE CHANGE IN C
 ALSTGCHG CURRENT MINUS TAKEOFF ALTIMETER (100TH IN HG)
 ALSTGABS ABSOLUTE VALUE OF ALSTG CHANGE (100TH IN HG)
 HGTEROR TRUE MINUS INDICATED ALTITUDE IN FEET
 HGTERABS ABSOLUTE VALUE OF ALTITUDE ERROR IN FEET

MO	HR	TEMPCHG		TEMPABS		ALSTGCHG		ALSTGABS		HGTEROR		HGTERABS	
		MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX	MEAN	MAX
JUL	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.1	68.1	12.2	68.1
	20	0.3	6.7	0.7	8.9	-1.3	5.0	1.5	10.0	1.2	53.7	9.6	81.5
	21	0.4	8.4	1.1	9.4	-2.5	10.0	2.6	14.0	-9.6	105.1	15.8	111.8
	22	0.1	7.8	1.3	11.6	-3.4	15.0	3.7	15.0	-20.4	149.6	25.0	149.6
AUG	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	57.6	12.0	57.6
	20	0.2	2.3	0.7	9.5	-1.6	6.0	1.7	7.0	-1.3	76.5	9.8	76.5
	21	0.3	5.0	1.0	10.6	-2.9	7.0	3.0	8.0	-14.0	66.7	18.0	72.3
	22	0.0	10.6	1.2	10.6	-3.7	5.0	3.8	11.0	-23.4	86.7	26.9	118.6
SEP	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.4	86.3	9.5	86.3
	20	0.4	3.9	0.7	5.0	-1.6	6.0	1.8	10.0	-3.9	114.9	12.2	114.9
	21	0.4	7.3	1.0	10.6	-2.8	9.0	3.0	9.0	-15.0	153.0	20.4	153.0
	22	0.1	6.7	1.0	8.9	-3.5	12.0	3.8	12.0	-22.8	181.5	28.8	181.5
OCT	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7	76.4	6.1	76.4
	20	0.4	6.1	0.7	6.1	-1.4	4.0	1.6	5.0	-4.4	95.6	13.2	95.6
	21	0.5	9.4	1.0	9.4	-1.9	7.0	2.6	10.0	-9.1	124.4	20.7	124.4
	22	0.1	8.8	1.0	8.9	-2.2	10.0	3.3	17.0	-13.8	134.0	29.1	147.8
NOV	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.9	94.2	7.7	94.2
	20	0.3	2.7	0.6	8.3	-1.3	6.0	1.9	10.0	-2.6	127.7	18.2	127.7
	21	0.3	3.4	0.8	10.5	-1.7	14.0	3.1	18.0	-5.3	184.5	28.4	184.5
	22	-0.1	3.8	0.9	12.2	-1.4	22.0	3.9	23.0	-5.0	222.3	38.2	222.3
DEC	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.2	117.3	9.8	117.3
	20	0.4	2.8	0.6	2.8	-1.1	8.0	1.9	8.0	0.8	135.7	19.7	135.7
	21	0.4	3.9	0.9	6.7	-1.1	14.0	3.1	14.0	1.5	190.7	29.9	190.7
	22	-0.0	6.1	1.0	7.8	-0.6	22.0	4.3	22.0	4.8	262.2	41.6	262.2

**Figure C-4 July-December Statistics for 2,000-foot Flight Level, Scott AFB.
Takeoff 1900Z (1300L), Landing 2200Z (1600L)**

BIBLIOGRAPHY

- Haltiner, G.J., and F. Martin, *Dynamical and Physical Meteorology*, McGraw-Hill, 1957.
- Huschke, R.E., *Glossary of Meteorology*, American Meteorological Society, Boston, 1986.
- Ivanov, V.I., *Altimeter Errors*, Air Force Systems Command, Foreign Technology Division, FTD-HT-23-1010-68, 1969.
- Kogler, T.R., *Modeling the Effects of the Use of GPS (Global Positioning System) Derived Altitude Indication in the C-17A Airdrop System*, Air Force Institute of Technology, School of Engineering, AFIT/GSO/ENS/89D-9, 1989.
- Oke, T.R., *Boundary Layer Climates*, Methuen-London and New York, 1987.
- Skinner, H.R., Jr., *The Altimeter Credibility Gap*, Federal Aviation Administration, Seventh Annual Aviation Maintenance Symposium, 1971.
- U.S. Standard Atmosphere*, National Aeronautics and Space Administration, United States Air Force, and United States Weather Bureau, October, 1976.
- Weather for Aircrews*, AFM 51-12, Vol I, Department of the Air Force, 1982.

GLOSSARY

AGL	above ground level
ALSTGABS	absolute values of hourly altimeter changes in 100ths of inches of Mercury
ALSTGCHG	hourly changes (current altimeter minus takeoff altimeter) in 100ths of inches of Mercury
C	celsius
g	gravity
h	height
Hg	mercury.
HGTERABS	absolute values of hourly altimeter errors in feet
HGTERROR	hourly altimeter errors (true altitude minus indicated altitude) in feet
ILS	instrument landing system
K	kelvin
LST	local standard time
mb	millibar
P	pressure
R	gas constant for dry air
sec	second
T	temperature
\bar{T}	mean temperature
T	virtual temperature
T_v	mean virtual temperature
TEMPABS	absolute values of hourly temperature changes in C
TEMPCHG	hourly changes (current temperature minus takeoff temperature) in C
z	height

DISTRIBUTION

AWS/DO, Scott AFB, IL 62225-5008	1
AWS/XTJ, Scott AFB, IL 62225-5008	1
AWS/XTX, Scott AFB, IL 62225-5008	1
375MAW/DOM, Scott AFB, IL 62225-5000	2
OL A, HQ AWS, Buckley ANG Base, Aurora, CO 80011-9599	1
SSD/MWA, PO Box 92960, Los Angeles, CA 90009-2960	1
OL-K, HQ AWS, NEXRAD Opnl Support Facility, 1200 Westheimer Dr. Norman, OK 73069	1
OL-M, HQ AWS, McClellan AFB, CA 95652-5609	1
Det 1, HQ AWS, Pentagon, Washington, DC 20330-6560	3
Det 2, HQ AWS, Pentagon, Washington, DC 20330-5054	3
Det 3, HQ AWS, PO Box 3430, Onizuka AFB, CA 94088-3430	1
Det 9, HQ AWS, PO Box 12297, Las Vegas, NV 89112-0297	1
1WW/DN, Hickam AFB, HI 96853-5000	3
11WS/DON, Elmendorf AFB, AK 99506-5000	1
20WS/DON, APO San Francisco 96328-5000	1
30WS/DON, APO San Francisco 96301-0420	1
2WW/DN, APO New York 09094-5000	3
7WS/DON, APO New York 09403-5000	1
28WS/DON, APO New York 09127-5000	1
31WS/DON, APO New York 09136-5000	1
3WW/DN, Offutt AFB, NE 68113-5000	3
9WS/DON, March AFB, CA 92518-5000	1
24WS/DON, Randolph AFB, TX 78150-5000	1
26WS/DON, Barksdale AFB, LA 71110-5002	2
4WW/DN, Peterson AFB, CO 80914-5000	3
2WS/DON, Andrews AFB, MD 20334-5000	21
5WW/DN, Langley AFB, VA 23665-5000	3
1WS/DON MacDill AFB, FL 33608-5000	1
3WS/DON, Shaw AFB, SC 29152-5000	1
5WS/DON, Ft McPherson, GA 30330-5000	1
25WS/DON, Bergstrom AFB, TX 78743-5000	1
AFGWC/SDSL, Offutt AFB, NE 68113-5000	3
USAFETAC, Scott AFB, IL 62225-5438	6
7WW/DN, Scott AFB, IL 62225-5008	3
6WS/DON Hurlburt Field, FL 32544-5000	1
15WS/DON, McGuire AFB, NJ 08641-5002	1
17WS/DON, Travis AFB, CA 94535-5986	1
Det 9, 17WS, Scott AFB, IL 62225-5000	3
3350 TCHTG/TTGU-W, Stop 62, Chanute AFB, IL 61868-5000	2
3395 TCHTG/TTKO-W, Keesler AFB, MS 39534-5000	2
AFIT/CIR, Wright-Patterson AFB, OH 45433-6583	1
NAVOCEANCOMDET, Federal Building, Asheville, NC 28801-2723	1
NAVOCEANCOMDET, Patuxent River NAS, MD 20670-5103	1
NAVOCEANCOMFAC, NAS North Island, San Diego, CA 92135-5130	1
COMNAVOCEANCOM, Code N312, Stennis Space Ctr, MS 39529-5000	1
COMNAVOCEANCOM (Capt Brown, Code N332), Stennis Space Ctr, MS 39529-5001	1
NAVOCEANO (Rusty Russum), Stennis Space Ctr, MS 39522-5001	2
NAVOCEANO, Code 9220 (Tony Ortolano), Stennis Space Ctr, MS 39529-5001	1
Maury Oceanographic Library (NOC), Code XJL, Stennis Space Ctr, MS 39529-5001	1
FLENUMOCEANCEN, Monterey, CA 93943-5006	1

Naval Postgraduate School, Chmn, Dept of Meteorology, Code 63, Monterey, CA 93943-5000.....	1
Naval Eastern Oceanography Ctr (Clim Section), U117 McCAdy Bldg, Norfolk, Norfolk, VA 23511-5000.....	1
Naval Western Oceanography Ctr, Box 113, Attn: Tech Library, Pearl Harbor, HI 96860-5000	1
Naval Oceanography Command Ctr, COMNAVMAR Box 12, FPO San Francisco, CA 96630-5000	1
Naval Oceanography Command Ctr, Box 31, USNAVSTA FPO New York, NY 09540-3000.....	1
Pacific Missile Test Center, Geophysics Division, Code 3253, Pt Mugu, CA 93042-5000	1
Dept of Commerce/NOAA/MASC Library MC5 (Jean Bankhead), 325 Broadway, Boulder, CO 80303.....	2
OFCM, Suite 300, 6010 Executive Blvd, Rockville, MD 20852.....	1
NOAA Library-EOC4WSC4, Attn: ACQ, 6009 Executive Blvd, Rockville MD 20852	1
NOAA/NESDIS (Attn: Nancy Everson, E/RA22), World Weather Bldg, Rm 703, Washington, DC 20233	1
NOAA/NESDIS (Attn: Capt Perrera, FB #4, Rm 0308, Suitland, MD 20746.....	1
Armed Forces Medical Intelligence Agency, Info Svcs Div., Bldg 1607, Ft Detrick, Frederick, MD 21701-5004	1
PL OL-AA/SULLA, Hanscom AFB, MA 01731-5000.....	1
Atmospheric Sciences Laboratory (SLCAS-AT-AB), Aberdeen Proving Grounds, MD 21005-5001	1
Atmospheric Sciences Laboratory (SLCAS-AS-1 310-2c), White Sands Missile Range, NM 88002-5501	1
Army Missile Command, ATTN: AMSMI-RD-TE-F, Redstone Arsenal, AL 35898-5250.....	1
Army Test & Eval Cmd, ATTN: AMSTE-TC-AM (RE) TCOM Met Team, Redstone Arsenal, AL 35898-8052....	1
Commander and Director, U.S. Army CEETL, Attn: GL-AE, Fort Belvoir, VA 22060-5546.....	1
6510 TESTW/TSTL, Edwards AFB, CA 93523-5000.....	1
RL/DOVL, Bldg 106, Griffiss AFB, NY 13441-5700	1
AFESC/RDXT, Bldg 1120, Stop 21, Tyndall AFB, FL 32403-5000	1
Technical Library, Dugway Proving Ground, Dugway, UT 84022-5000	1
NWS W/OSD, Bldg SSM C-2 East-West Hwy, Silver Spring, MD 20910.....	1
NWS Training Center, 617 Hardesty, Kansas City, MO 64124.....	1
NCDC Library (D542X2), Federal Building, Asheville, NC 28801-2723.....	1
NIST Pubs Production, Rm A-405, Admin Bldg, Gaithersburg, MD 20899	1
JSOC/Weather, P.O. Box 70239, Fort Bragg, NC 28307-5000	1
75th RGR (Attn: SWO), Ft Benning, GA 31905-5000	1
HQ 5th U.S. Army, AFKB-OP (SWO), Ft Sam Houston, TX 78234-7000.....	1
DTIC-FDAC, Cameron Station, Alexandria, VA 22304-6145	2
AUL/LSE, Maxwell AFB, AL 36112-5564	1
AWSTL, Scott AFB, IL 62225-5438	35